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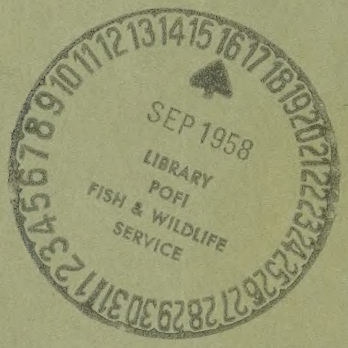

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4. The author is asked to follow this publication for forms of headings and references, etc.
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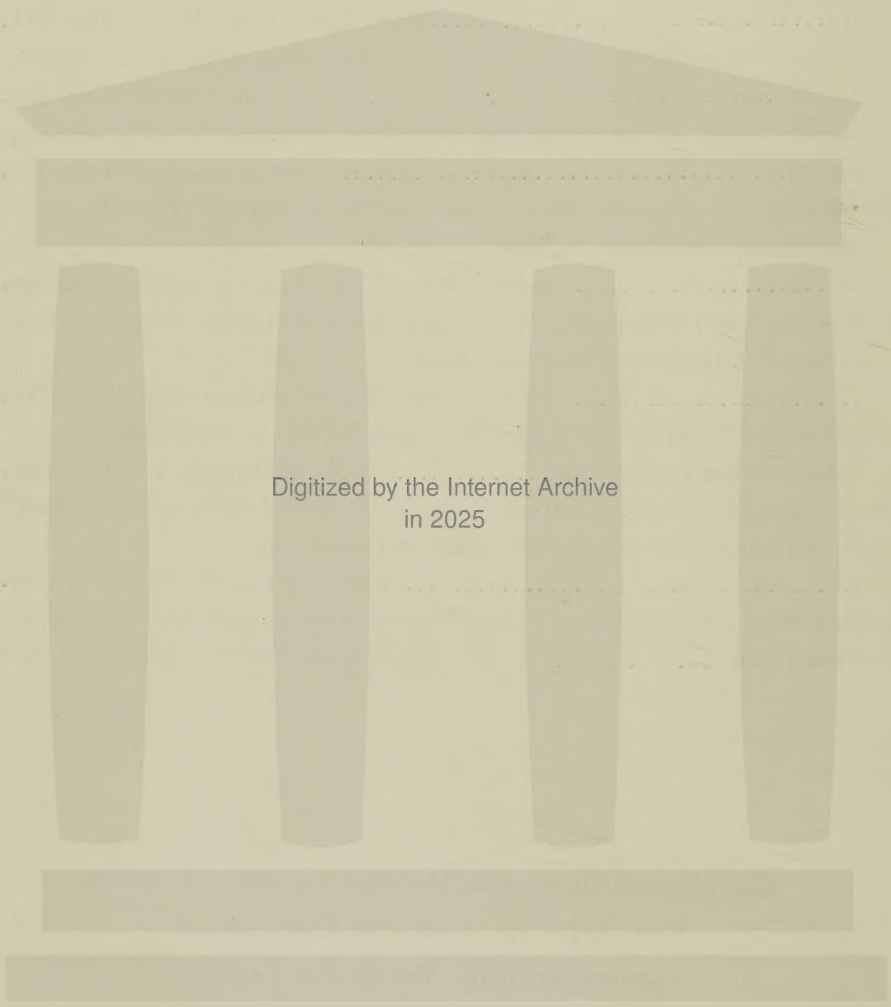
Corrigendum to the Preface by Dr. Hatai to Vol. III, No. 1 of the Records of Oceanographic Works in Japan.

Replace the sentence "The Vol. II, No. 4 of the Journal was thus published by the Japan Science Council" by "The Vol. III, No. 1 of the Journal was thus published by the Science Council of Japan." The issue which followed Vol. II, No. 3 is Vol. III, No. 1, not Vol. II, No. 4.



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Records of Oceanographic Works
in Japan Vol. 4, No. 1,
December 1957

A Supplementary Note on the Foaming of Sea Water

By
Tomosaburo Abe
(Oceanographical Laboratory, Meteorological Research Institute)

1. Introduction

It is a well known fact that sea water has more intense foaming power than fresh water, and the phenomena concerning the foaming of sea water, for example, the foaming on ocean surface and wave crest produced by wind actions, the foaming in current rips, the foam line following the contours of an island and so on, give us many important and very interesting problems in local oceanography. Therefore, in order to obtain fundamental and practical knowledges on foaming of sea water, the present author treated the problem experimentally as follows.

2. Relation between the height of foam layer and the temperature

Experimental procedure is as previously reported by the author in this journal (N.S. Vol. 1, No. 2, 1953).

The experiments were performed in the range of temperatures from 33 to 3°C at a constant chlorinity concentration 18.93 ‰.

The height of the foam layer of sea water H increases slightly with increasing temperature in a linear relation as shown by the following formula:

$$H=a+b\cdot\theta \qquad (1)$$

where θ is the temperature of sea water, a and b are constants respectively, the values of which depend upon the concentration of sea water. All the samples show the similar tendency in relation to temperature, and so, for example, the case of sea water having the chlorinity concentration 18.93 ‰ is expressed as follows:

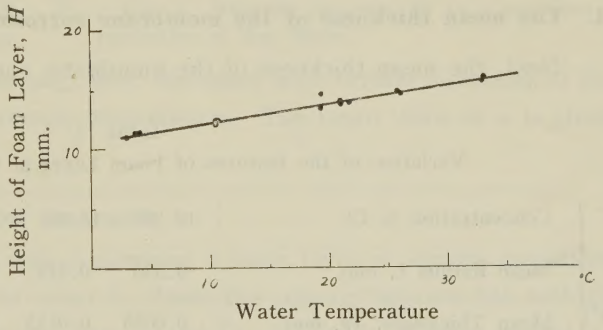

Fig. 1. Relation between the height of Foam Layer and Temperature, Chlorinity of Sea Water: 18.93 ‰.

$$H=10.5+0.21\,\theta \qquad (2)$$

Though the height of foam layer is related with the temperature, the effect of it is slightly smaller.

3. Relation between the height of foam layer and the chlorinity concentration of sea water

For the samples, a filtered natural sea water (19.37 ‰ Cl) and various ones which were prepared by diluting this sea water in various degrees, were used at constant temperature to obtain the relation between the height of foam layer and its chlorinity concentration.

Under a constant temperature, H increases exponentially with increasing chlorinity as shown in Fig. 2. In this Figure, three cases of temperatures 10, 20 and 30°C were shown. H is affected by variations of chlorinity in a comparatively large degree at low concentration less than 5 ‰ Cl, but in a comparatively small degree at high concentration. Thus we can estimate the height of foam layer produced at a desired temperature and chlorinity concentration.

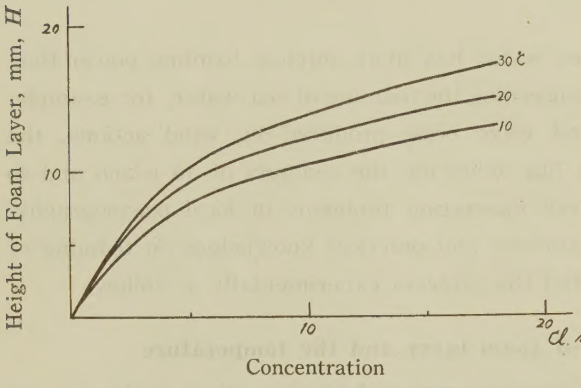

Fig. 2. Relation between the Height of Foam Layer and the Chlorinity of Sea Water.

4. The mean thickness of the membrane surrounding a bubble

Next, the mean thickness of the membrane surrounding a bubble was roughly

Table 1
Variation of the features of Foam Layer at the temperature 20°C.

a*	Concentration ‰ Cl	19.26	18.46	16.05	14.42	12.82	9.63
	Mean Radius $\bar{r}$, mm	0.330	0.315	0.365	0.388	0.397	0.506
	Mean Thickness, $\overline{dr}$, mm	0.0055	0.0115	0.0096	0.0230	0.0250	0.0234
	Ratio $\sigma\left(\equiv\frac{d\bar{r}}{\bar{r}}\right)$	0.0167	0.0365	0.0263	0.0592	0.0630	0.0463
b*	Mean Radius, $\bar{r}$ mm	0.530	0.432	0.542	0.583	0.600	—
	Mean Thickness, $\overline{dr}$ mm	0.0618	0.0162	0.0362	0.0520	0.0113	—
	Ratio $\sigma\left(\equiv\frac{\overline{dr}}{\bar{r}}\right)$	0.117	0.0375	0.0667	0.0890	0.0188	—

where a* are values at 3 sec. after a vibration stopped,
b* are values at 9 sec. after a vibration stopped.

estimated by using successive photographs of a foam layer. The procedure is as follows:

By means of the difference between the sea water level at the initial stage and the lowered level of it at the grown-up stage of a foam layer, the volume of sea water converted into the foam layer is calculated, then the mean thickness of membrane surrounding a bubble, $\overline{dr}$, is calculated as follows:

$$\frac{4}{3}\pi(\bar{r}+\overline{dr})^3-\frac{4}{3}\pi\bar{r}^3=dv$$

$$\therefore\ \overline{dr}=\frac{dv}{4\pi\bar{r}^2}$$

where dv is the volume of sea water to form only one bubble, $\bar{r}$ the mean radious. Though the value of $\overline{dr}$ obtained by such a simple method as above may be a rough one of course, it will give some notion on the order of magnitude of the thickness of the membrane. The calculated values of $\overline{dr}$ were tabulated in Table 1. From this table, the thickness of the membrane at the initial stage seems to become thinner with increasing chlorinity (Fig. 3). The ratio (σ) of $\overline{dr}$ to $\bar{r}$ increases gradually up to the maximum at 12.82 ‰ Cl with increasing chlorinity, then decreases with further increasing of the chlorinity. This is a very interesting phenomenon. The mean value of σ is about 0.04.

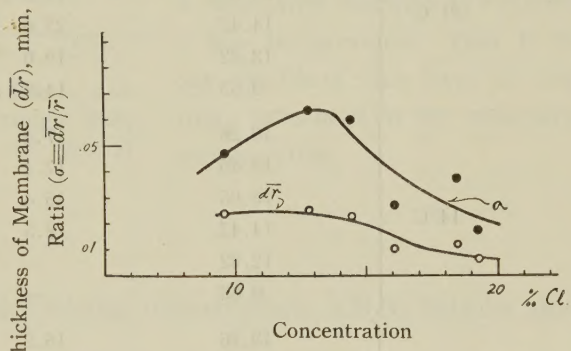

Fig. 3. Relation between $\overline{dr}$ or σ and Concentration of Sea Water.

5. Stability of a foam layer of sea water

The obtained experimental data concerning a foam layer at various conditions were tabulated in Table 2. In order to obtain the relation between the half-life (τ) of foam layer and the chlorinity, data (τ and Cl) in Table 2 were plotted as shown in Fig. 4. In this figure the straight lines with arrows were drawn to show the general tendency. From Fig. 4 we obtain the following results: In the case of sea water having chlorinity concentrations higher than 13 ‰, the value of τ is larger than that in the case of lower concentrations; that is, the foam layer is more stable in the former case than in the latter, and it does not decay easily. It was previously reported by us that foam is easily produced when the chlorinity of sea water has a comparatively large value, i.e. a value larger than 13 ‰ Cl., and the foam produced lasts longer. Thus, it is considered that in sea regions with large chlorinity concentration, the white-chops easily appear, while in sea regions

Table 2
Experimental values on the foaming of sea water.

Water Temperature	Concentration ‰ Cl.	h_0 (mm)	k	τ (sec)
29°C	19.26	22.5	0.143	4.8
	18.46	24.6	0.170	4.1
	16.05	24.4	0.166	4.2
	14.42	19.3	0.137	5.1
	12.82	18.5	0.145	4.8
	9.63	20.0	0.200	3.6
21°C	19.26	23.8	0.124	5.5
	18.46	25.5	0.128	5.4
	16.05	19.3	0.099	7.1
	14.42	23.0	0.131	5.3
	12.82	19.0	0.109	6.4
	9.63	14.3	0.214	3.2
14°C	19.26	17.4	0.071	10.0
	18.46	17.4	0.071	9.1
	16.05	16.4	0.084	8.2
	14.42	18.5	0.094	7.5
	12.82	—	—	—
	9.63	—	—	—
4°C	19.26	16.2	0.071	10.0
	18.46	13.7	0.047	14.5
	16.05	15.2	0.058	11.8
	14.42	14.7	0.049	12.6
	12.82	—	—	—
	9.63	15.8	0.097	7.4

where h_0 is the height of foam layer at initial,
k the decay constant, τ the half-life.

with comparatively low chlorinity, i.e. lower than 9 ‰ Cl., the white-chops do not easily appear.

Using the straight lines with arrows in Fig. 4, we could calculate the value of $\partial\tau/\partial$Cl, that is, the values of varriations of the half-life against that of the chlorinity concentrations. From Table 3, we see that the value of $\partial\tau/\partial$Cl increases rapidly as the temperature decreases, for example, this value at 29°C is 6×10^{-2}(sec/‰ Cl), it becomes 51×10^{-2}(sec/‰ Cl) at 4°C, which is about 9 times larger than the former value. The value of $\partial\tau/\partial$ Cl is a comparatively small one at high temperature of sea water, it seems to indicate small variation in half-life at high temperature, that is to say, at a comparatively high temperature, the life of foam layer has the same small value whatever the chlorinity concentration of the sea water is large or small. On the contrary, the value of $\partial\tau/\partial$ Cl has a very large one at a low

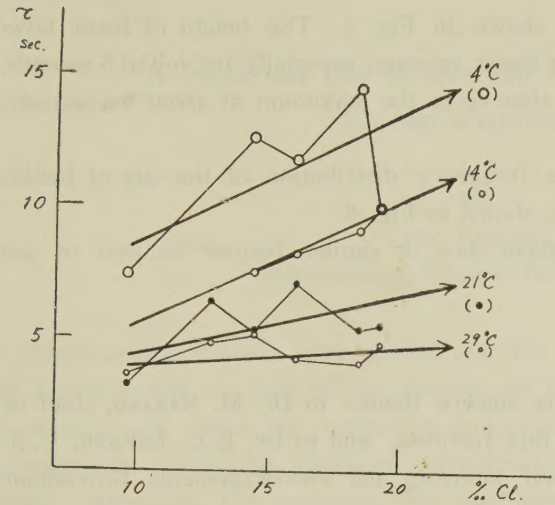

Fig. 4. Relation between the Half-Life (τ) and the Chlorinity of Sea Water, the straight lines with arrows are drawn to show the general tendency.

Table 3

Experimental values of $\frac{\partial \tau}{\partial Cl}$

Temperature °C	$\frac{\partial \tau}{\partial Cl} \times 10^2$
29	6
21	23
14	45
4	51

temperature. It seems to indicate a very large variation in τ at such a low temperature. That is to say, the life of foam layer is very much influenced by the chlorinity concentration.

6. Foaming of NaCl solution

Mean life of foam layer of NaCl solution (concentration: 3.54 N) lasts for about 8 seconds at temperature 15°C.

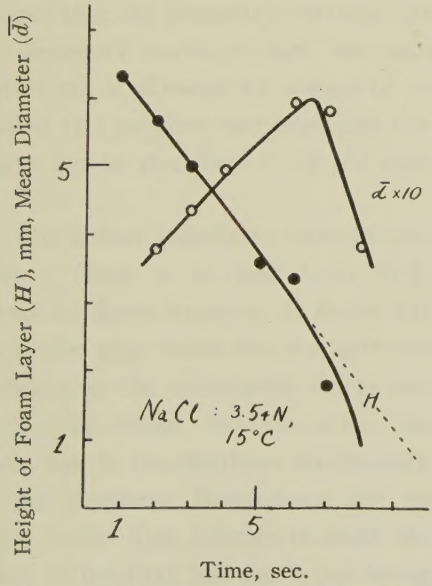

Fig. 5. Change of Bubbles of NaCl solution.

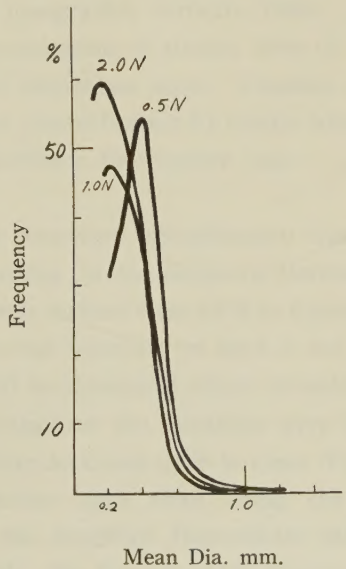

Fig. 6. Frequency Distribution of the size of Foam of NaCl solution.

The change of bubble size is shown in Fig. 5. The height of foam layer decreases with the lapse of time in a linear relation, especially for initial 5 seconds, and its mean radious increases with time up to the maximum at about 6.5 seconds, then decreases rapidly.

Next, the relation between the frequency distribution of the size of bubble and concentration of NaCl solution is shown in Fig. 6.

The frequency distributions of them show a similar feather as that of sea water.

7. Acknowledgement

The author wishes to express his sincere thanks to Dr. M. NAKANO, chief of the Oceanographical Laboratory of this Institute, and to Dr. E. C. LaFOND, U. S. Navy Electronics Laboratory, for their interests and encouragements throughout this work.

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A Note on the Westward Intensification of Ocean Current

By
Jiro Fukuoka
(Meteorological Research Institute, Tokyo)

1. Many oceanographers have pointed out that strong ocean currents, for example, the Kuroshio and the Gulf Stream develop on the western edge of ocean. These phenomena are called the westward intensification by Stommel. He is the first scientist who studied the westward intensification from the theoretical viewpoint (1948). Assuming the rectangle sea and homogeneous water, he obtained the balance between the planetary vorticity and wind stress.

Munk (1950) studied the same problem under strict assumptions. But a question about the westward intensification is still remaining. Because, if the planetary vorticity is the main cause of occurrence of westward intensification, it should be present in both hemispheres. But actually, the westward intensification can not be seen clearly in the Southern Hemisphere. Neumann also has cast questions about the uncertainty of the westward intensification in the Southern Hemisphere. He studied the relation between the planetary vorticity and the motionless layer. He showed that the planetary vorticity cancells the topographic vorticity (1956). After all, planetary vorticity does not cause the concentration of stream lines of ocean current but is adjusted by change of thickness of motionless layer. Charney (1955) studied this problem and explained the westward intensification by inertia boundary theory but he discussed it for the case of the Northern Hemisphere only.

2. The author intends to state the cause of the westward intensification quantitatively. There is no land from 40°S to Antarctica in the Southern Hemisphere except for South America. In South America there is no land from 54°S to Antarctica. So in the area where the westerly predominates the boundary of land is not seen. In this area the circumpolar ocean current should be developed which already was studied by Munk. So that in the Southern Hemisphere the clockwise gyre is not seen, but in the Northern Hemisphere the counterclockwise gyre is clear (Fig. 1). In the Northern Hemisphere the counterclockwise gyre shall bring the cold water in the high latitude to south sea, but in the Southern Hemisphere the cold water in the high latitude is not brought to north. By the act of the counterclockwise gyre the discontinuity of sea water is to appear in the western edge of the ocean and then this discontinuity line along the western edge of ocean occupied

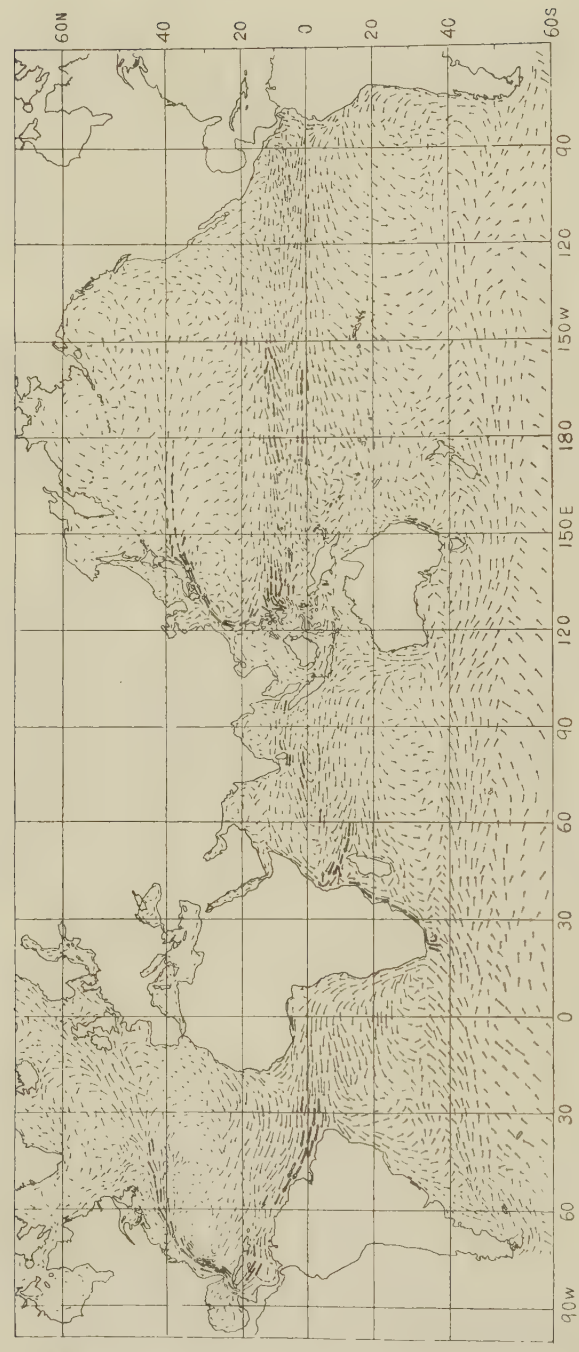

Fig. 1. Current chart in summer. [from МОРСКОЙ АТЛАС ТОМ II]

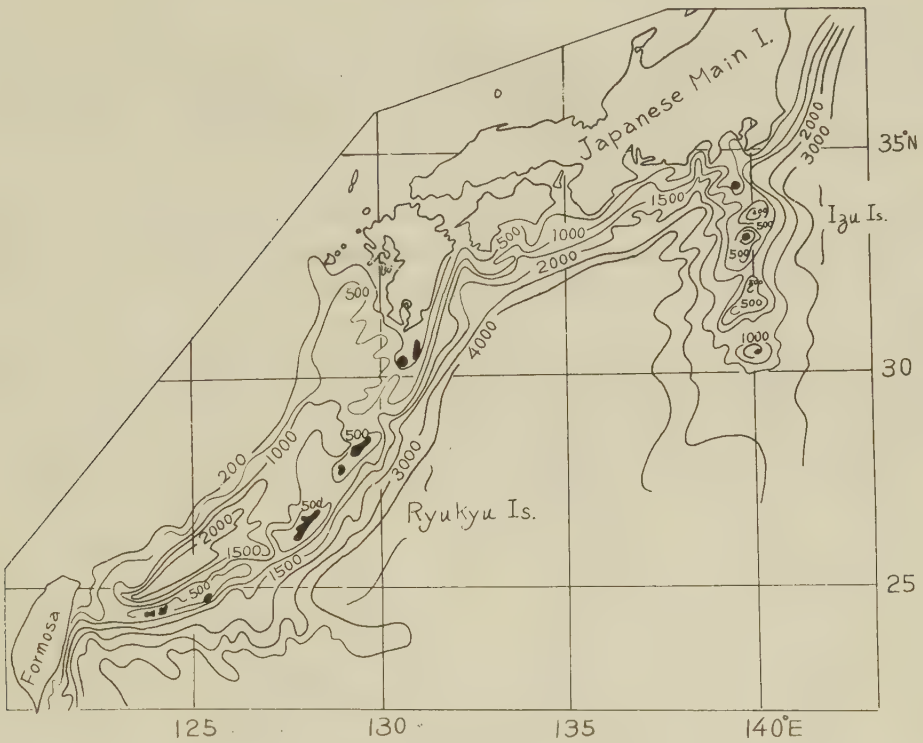

Fig. 2. Bathymetric chart near Japan. (Depth in meter)
[from No. 1001 chart, Hydro. Dep. Japan]

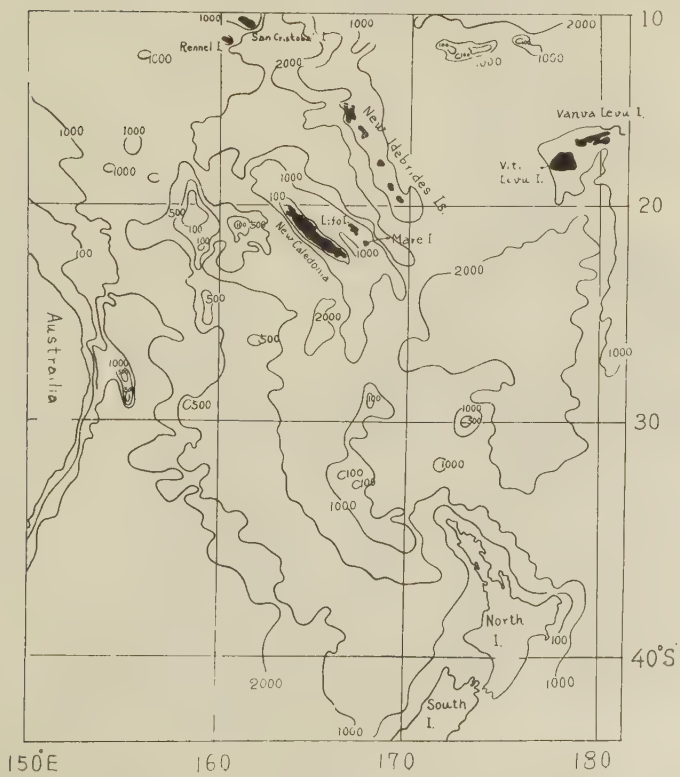

Fig. 3. Bathymetric chart near Australia. (Depth in fathom)
[from No. 825 (2nd Ed, 1946) chart, Hydro. Off. U.S. Navy]

in more southern part than in the central or eastern part of ocean. Especially, the horizontal gradient of density is steeper in the western part than in the central or eastern part of ocean. So the existence of the counterclockwise gyre owing to enclosed ocean may be related with the westward intensification.

3. It is not enough to explain the westward intensification only by planetary vorticity, because in the South Atlantic Ocean the strong current on the western edge is not seen at all but in the South Indian Ocean or the South Pacific Ocean, rather strong currents are seen on the western edges.

Comparing the current chart with the bathymetric chart, we can notice that the place where the westward intensification occurs is almost coincident with the shallow place on the western edge of the ocean.

In the North and South Pacific Oceans the submarine ridges are indicated on

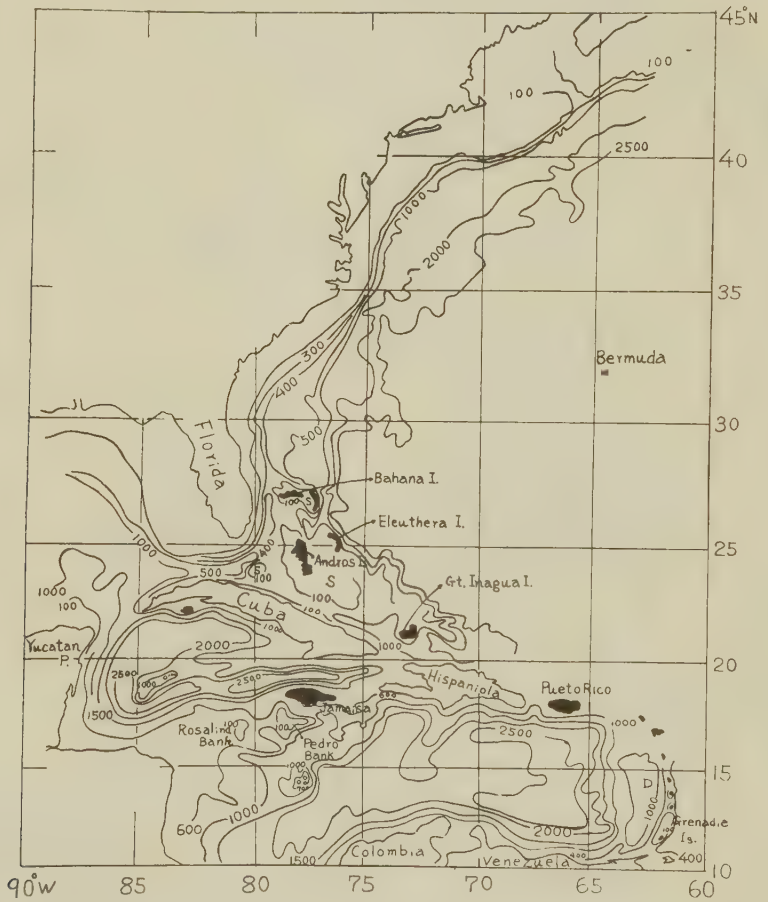

Fig. 4. Bathymetric chart near America. (Depth in fathom)
[from Nos. 1290 (108th Ed) and 1411 (92 Ed) charts, Hydro. Off. U.S. Navy]

the western edges, especially in the North Pacific Ocean the extreme submarine ridge along the Japanese Islands is indicated. In the North Atlantic Ocean the extreme submarine ridges are indicated in the Florida Straits, the sea near the Pedro Bank and Rosalind Bank and the sea near the Grenadine Islands. But in the South Atlantic Ocean the submarine ridge is not seen at all (Figs. 2, 3, 4 and 5). In the Indian Ocean the Mozambique current is strong. In the Mozambique Channel the extreme submarine ridge is also seen between the Madagascar Island and Africa (Fig. 6). On the contrary we can see that on the eastern edge of the ocean there is no steep submarine ridge (Fig. 7).

From the above stated fact we can infer that the strong ocean current on the western edge of the ocean has closely related with the bottom topography. Besides, from these facts it is indicated that the planetary vorticity does not cancell the

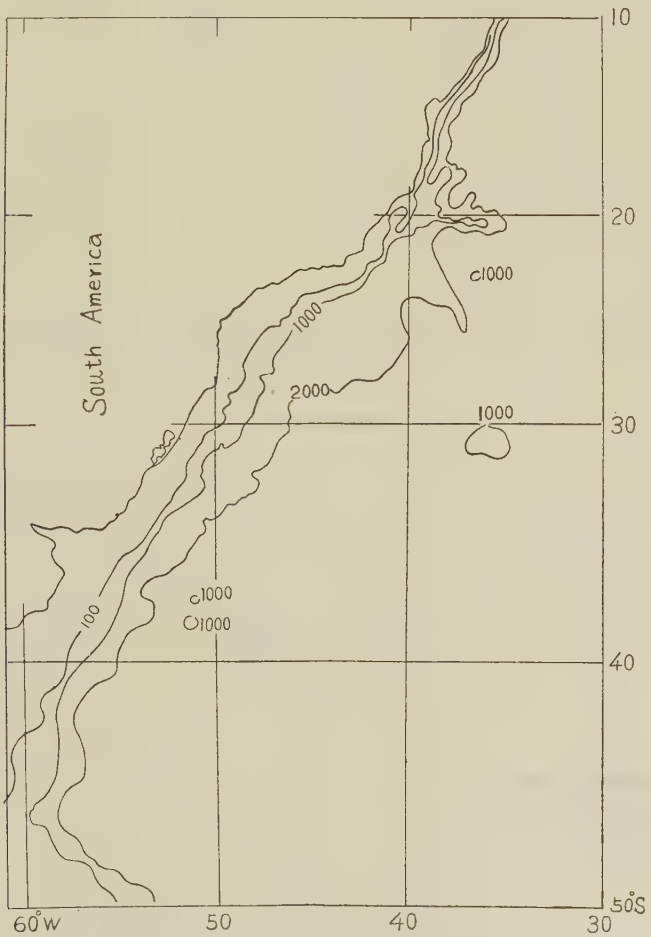

Fig. 5. Bathymetric chart near South America. (Depth in fathom)
[from Nos. 957 (2nd Ed) and 958 (3rd Ed) charts, Hydro. Off. U.S. Navy]

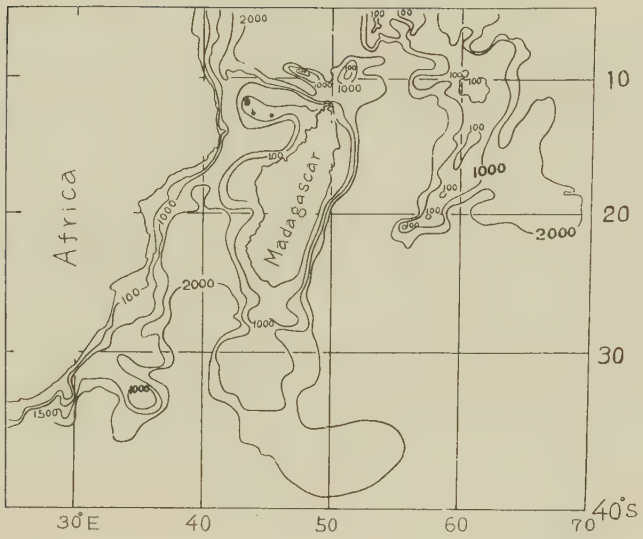

Fig. 6. Bathymetric chart near Africa. (Depth in fathom)
[from No. 5446 (3rd Ed) chart, Hydro. Off. U.S. Navy]

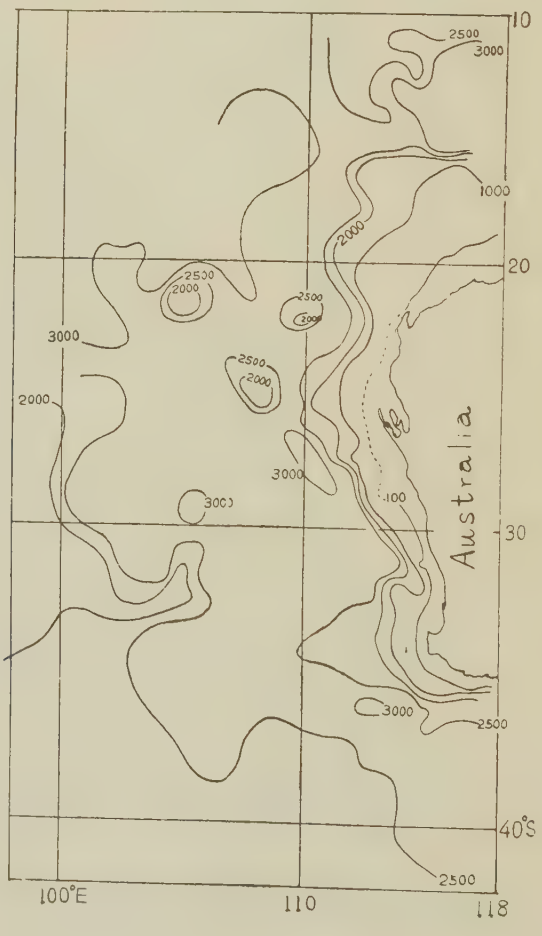

Fig. 7(a). Bathymetric chart on the eastern edge of the Ocean. (Depth in fathom)
[from No. 5446 chart]

topographic vorticity but the topographic vorticity accelerates the planetary vorticity near submarine ridge on the western edge of ocean.

The author thinks that the westward intensification should be studied from several viewpoints of the enclosed ocean, zonal ocean and bottom topography.

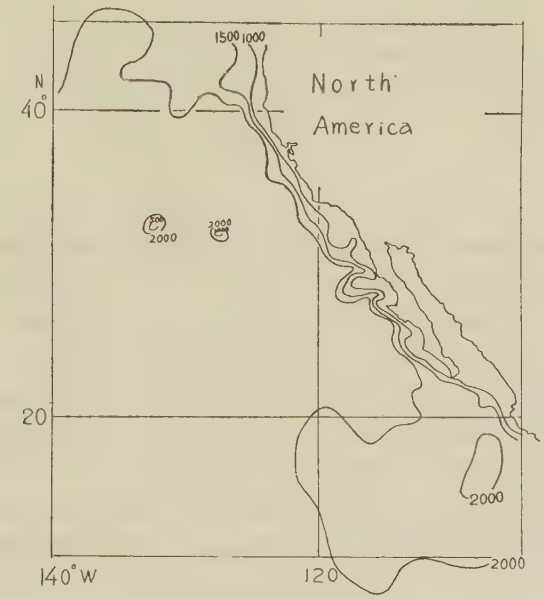

Fig. 7(b). Bathymetric chart on the eastern edge of the Ocean. (Depth in fathom) [from No. 809 chart, Hydro. Dep. Japan]

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Northward Flow in Lower Layers as an Indicator of Coastal Upwelling

By
Kozo Yoshida and Mizuki Tsuchiya
(Geophysical Institute, Tokyo University, Tokyo)

1. Introduction

Some vertical sections taken normal to the California coasts clearly show that the isotherms (or isopycnals) in the upper layers above 100 to 200 m conspicuously rise toward the coast while those in the lower layers below the depth of 200 to 500 m fall toward the coast. The similar remarkable features of isotherms or isopycnals are frequently encountered especially in coastal regions where upwelling takes place. Defant (1936) presented the similar type of pictures along the western coasts of South Africa. Several east-west sections from NORPAC temperature data reveal the similar conditions at the eastern edge of the North Pacific (Fig. 1). The feature may then be described by its appearance as something like a "vertical divergence of isotherms" at certain intermediate depths, say, between 200 m and 500 m. Note that relatively homogeneous water is present at these intermediate depths.

Such a feature might give an impression that onshore flow in certain subsurface layer, as it strikes the coast, gives rise to upwelling in the layers above and sinking in the layers below. In fact, Defant gave in that figure (1936) a schematical picture of vertical circulation more or less based on this interpretation. However, there might be an alternative interpretation which will be discussed in the present paper. Take an example of California waters. The fall of isotherms toward the coast in the layers over several hundred meters above 1000 meter level indicates the presence of northward current at and somewhat above these depths. If this distribution of temperature revealed on the section were not associated with very small scale disturbances but with somewhat large scale in space as well as in time, it should be possible that the northward current at these greater depths associates the horizontal convergence of mass which completely compensates the divergence of mass in the upper 100 to 200 meters. This would be true, provided that the geostrophic flow below 1000 m is negligible and that the simple vorticity balance in the lower layers (between horizontal divergence and planetary vorticity) is valid. The validity of this balance has been examined for the California waters (Yoshida and Mao, in press), and other areas by Stommel (1956). If this is the case, the stated feature is considered to contain the upward

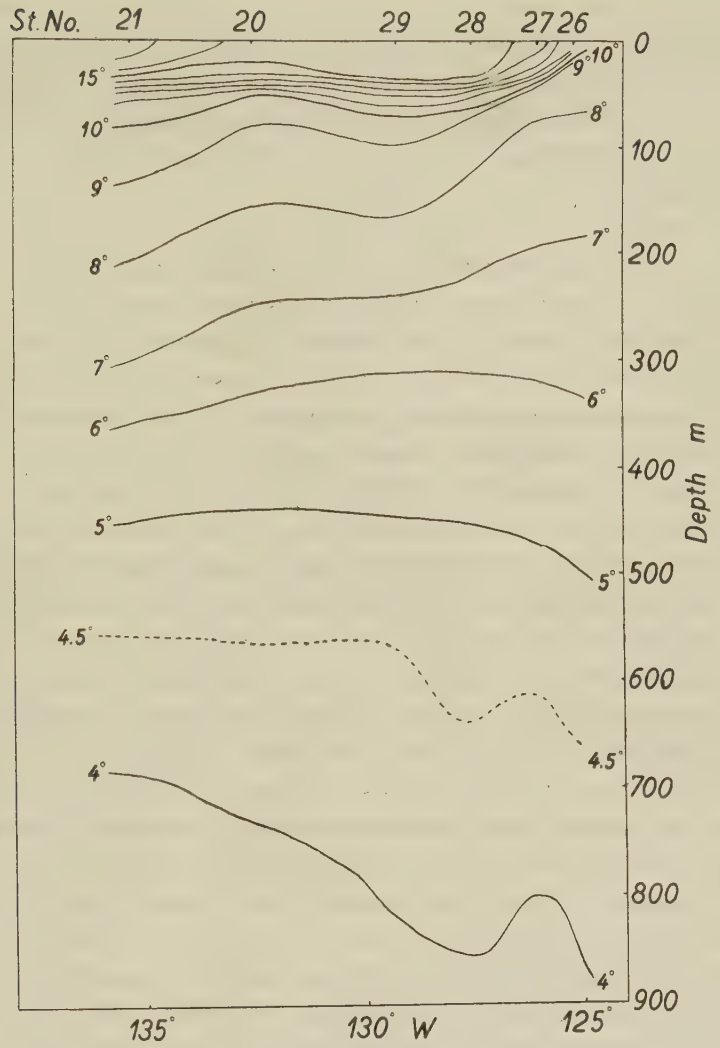

Fig. 1. Temperature section along 44°N latitude.
NORPAC, CCOFI cruise 5508, August, 1955.

motion in the lower layers to compensate the upwelling in the surface layer, so that this dynamical result is contrary to the first intuitive impression on "sinking" in the lower layers. However, the features revealed on the vertical section may include very concentrated coastal process and some particular phase of transient process. The relationship between vertical motion and meridional currents might not in general be applicable to such an accelerated system. As a boundary phenomenon, an upwelling process concentrated very close to a coast (within a distance less than 100 km from the coast) was discussed in relation to the wind parallel to the coast. (Yoshida, 1955). The relation between the upwelling and the meri-

dional component of horizontal flow in lower layers has not been discussed for such coastal process. If it be found that the northward flow in the lower layer should associate the upward flow in the layers above (without considerable phase difference) also for such accelerated system, the proposed interpretation for individual sections would be possible and so one could detect upwelling from the individual temperature sections.

Let us try to describe certain transient state of the mass adjustment. At first, wind-generated horizontal divergence in the upper layer causes surface upwelling in one to two days. Immediately producing an upward displacement of the thermocline, this necessarily leads to the changes in pressure in the lower layer and consequently in motion in the lower layer. The upward motion is required just beneath the interface and consequently convergence in deep horizontal flow. At earlier stage (perhaps **time scale** × **length scale** $\sim \beta^{-1} \sim 5 \times 10^{12}$ sec. cm), positive vorticity is created or accelerated by this convergence. Within such a vorticity field, the east-side region tends to increase poleward component of flow relatively to the west-side region. If the vorticity is small enough, the established state will perhaps be given by a poleward flow which balances the upward motion. For the large vorticity field near the coast, on the other hand, the tendency of causing convergence in the lower layer through mixing of vorticity is greater than that through planetary vorticity. If this is the case, the upward motion could be associated even with the equatorward flow over whole region. Any of transient conditions (actual situations) are intermediate between the above two, so that the observed flow in the lower layer would not always be northward when upwelling takes places in the upper layer. Before the established state is reached, or when the motion is periodic in time with relatively short period, there would not be well-developed northward flow in the lower layer. It is examined in the present work how the deep northward flow could correspond to the upwelling in the upper layer for periodic changes with various lengths of periods. For this purpose, it seems to be necessary to consider a role of mixing for the motions with periods longer than certain lengths. Slow rate of mixing would be sufficient to play a significant role on the adjustment process. The magnitude of lateral eddy diffusivity is obscure and furthermore the introduction of this effect will make the analytical treatment somewhat involved, so that a simplified form of mixing is employed here. Concerning the magnitude of mixing, certain values appear to be reasonable which lead to satisfactory explanation for the observed annual variations in mean sea level along the Pacific coasts of the North America. The solutions of the present problem depend essentially upon the magnitude of mixing.

2. Theory

The model considered here consists of a rotating two-layered ocean which has

a meridional coastal boundary at its eastern edge and is of constant depth in the equilibrium state. The two layers of homogeneous water are separated by a surface of discontinuity representing the mean thermocline. The dynamical equations are

$$-fv_1=g\frac{\partial z_0}{\partial x} \tag{1}$$

$$\frac{\partial v_1}{\partial t}+fu_1=\frac{\tau_y}{H_1}-\alpha v_1 \tag{2}$$

$$-fv_2=g\frac{\partial}{\partial x}(z_0+h\Delta\rho) \tag{3}$$

$$\frac{\partial v_2}{\partial t}+fu_2=-\alpha v_2 \tag{4}$$

where x-axis points eastward and y-axis northward; t is time; u_i and v_i $(i=1, 2)$ are the velocities in the x and y directions respectively; H_1 is the equilibrium thickness of the upper layer; z_0 is the deviation of the free surface from its equilibrium position, g is gravity; h is the deviation of the interface from its equilibrium position; $f=2\omega$ sin (latitude) is the Coriolis parameter; ω is the angular speed of the earth's rotation; τ_y is the y component of wind stress applied on the ocean surface; $\Delta\rho=\rho_2-\rho_1$; ρ_1 and ρ_2 are the density of the upper and lower layer respectively.

The vorticity equations obtained from the above equations are

$$\frac{\partial\zeta_1}{\partial t}-\frac{f}{H_1}w+\beta v_1=-\alpha\zeta_1 \tag{5}$$

$$\frac{\partial\zeta_2}{\partial t}+\frac{f}{H_2}w+\beta v_2=-\alpha\zeta_2 \tag{6}$$

where ζ_1 and ζ_2 are the relative vorticities of the upper and lower layers respectively; H_2 is the equilibrium thickness of the lower layer; $\beta=df/dy$. It is assumed that the motions are independent of the y-coordinate. The integration of the equation of continuity yields

$$w=\frac{\partial h}{\partial t}+\alpha h \tag{7}$$

In the above equations, mixing terms are represented by

$$-\alpha v\,,\quad -\alpha h\,,\qquad \text{\& etc.}$$

in place of more common expressions

$$B\frac{\partial^2 v}{\partial x^2}\,,\quad B\frac{\partial^2 h}{\partial x^2}\,,\qquad \text{\& etc.}$$

This replacement may require further explanation and discussion, but tentatively let us accept the very naive concept of something like a resistance proportional to a velocity.

It is assumed that all quantities vary with time as $\mathrm{Exp}(i\sigma t)$. The boundary condition that u_1 and u_2 vanish at the coast ($x=0$) gives

$$\left.\frac{\partial h}{\partial x}\right|_{x=0} = \frac{f}{gH_1\Delta\rho}\frac{\tau_y|_0}{i\sigma+\alpha} \tag{8}$$

Let us consider the frequencies of the variations ($\sigma=2\pi/\text{period}$) lower than 10^{-6} sec^{-1}.

The order of magnitude for α is assumed to be $10^{-6}\,\text{sec}^{-1}$, since there are some reasons to have this value as discussed later.

Put
$$E=\frac{\beta}{2\kappa(\sigma^2+\alpha^2)}$$

where
$$k=\frac{f}{\sqrt{gH_1\Delta\rho}}$$

For the frequency range under consideration, one can readily see*

$$E\sigma \ll 1 \quad \text{and} \quad E\alpha \ll 1$$

Then the approximate solutions for h, w and v_2 are obtained as given by (9), (10) and (11), if the wind stress at the coast is assumed to be

$$\tau_y|_{x=0} = |\tau_y|_0 \cos\sigma t$$

The solutions are

$$h \sim \frac{|\tau_y|_0}{\sqrt{gH_1\Delta\rho(1+H_1/H_2)}}\frac{e^{kx}}{\sqrt{\alpha^2+\sigma^2}}\cos\left[\sigma t+\frac{\beta\sigma}{2(\alpha^2+\sigma^2)}x-\tan^{-1}\frac{\sigma}{\alpha}-\tan^{-1}E\sigma\right]$$

$$w \sim \frac{|\tau_y|_0}{\sqrt{gH_1\Delta\rho(1+H_1/H_2)}}e^{kx}\cos\left[\sigma t+\frac{\beta\sigma}{2(\alpha^2+\sigma^2)}x-\tan^{-1}E\sigma\right]$$

$$v_2 \sim -\frac{|\tau_y|_0}{H_2(1+H_1/H_2)}\frac{e^{kx}}{\sqrt{\alpha^2+\sigma^2}}\cos\left[\sigma t+\frac{\beta\sigma}{2(\alpha^2+\sigma^2)}x-\tan^{-1}\frac{\sigma}{\alpha}\right]$$

where
$$E=\frac{\beta}{2\kappa(\alpha^2+\sigma^2)}$$

It is seen that the above solutions do not fulfill exactly the boundary condition at the coast for the lower layer. However, it can be proved that this discrepancy is practically unimportant and the solution can be justified as far as the present approximation is concerned.

It follows from the above solutions that northward flow occurs in the lower

* The following numerical values are used: $\beta=2\times10^{-13}\,\text{sec}^{-1}\,\text{cm}^{-1}$; $f=10^{-4}\,\text{sec}^{-1}$; $H_1=\frac{1}{2}\times10^4\,\text{cm}$; $(\Delta\rho/\rho_1)=2\times10^{-3}$.

layer when the thermocline rises with a phase lag of

$$\tan^{-1} E\sigma .$$

With the numerical values assumed before, the phase lag is at largest as small as 1/20 radian or as 1/125 of the period length. For annual variations, for example, the lag is only 3 days. **Such a small phase difference is negligible in practice, so that northward flow in the lower layer should correspond to the rise of thermocline as far as synoptic charts from ordinary oceanographic observations are referred to.** It should be noted that practically simultaneous occurrence of the deep northward current and the rise of thermocline in the coastal region looks similar as the occurrence in larger-scale quasi-steady conditions, but that the mechanism for the coastal processes differs materially from that for the larger-scale balanced motions. The phase difference between the rise of thermocline and the upwelling is

$$\tan^{-1} \frac{\sigma}{\alpha}$$

which depends somewhat upon the period considered. For the frequencies lower than 2×10^{-7}, which corresponds to the annual period, the phase difference is at largest as small as 1/5 radian or as 1/31 of the period length.

2.1. Comments on the assumed value for α

The assumption which might be most serious in the above considerations is the one that α is of the order of magnitude as large as $10^{-6}\,\mathrm{sec}^{-1}$. A physical significance of this assumed value for α is obscure, while this should be essential to the result. However, a discussion on a possible explanation for the observed annual oscillation in mean sea level at the Pacific coasts of North America appears to give $\alpha \sim 10^{-6}\,\mathrm{sec}^{-1}$ as will be described in the following section. The coefficient α assumed here may correspond to the coefficient of effective internal friction, r [sec^{-1}], assumed by G. Neumann (1955), who states in that paper that "—the value of 10^{-6} for r seems to be a fairly reliable average value,—". This value of α might also be interpreted by assuming $\alpha = Bk^2 (\sim B/L^2)$, in which $k^2 \sim 10^{-12}\,\mathrm{cm}^{-2}$ and $B \sim 10^6\,\mathrm{cm}^2\,\mathrm{sec}^{-1}$, corresponding to $\alpha \sim 10^{-6}\,\mathrm{sec}^{-1}$. This value for B usually defined as a lateral mixing coefficient is not considered unreasonable. The values of the coefficient determined to account for the observations in the equatorial Pacific were also of the order of $10^{-6}\,\mathrm{sec}^{-1}$ (Yoshida et al, 1953: Wyrtki, 1956).

3. Annual variations in mean sea level

According to a study of Pattullo et al (1955), the mean annual oscillation in sea level along the Pacific coasts of the North American Continent reveals the am-

plitudes of 5 to 10 cm. The lowest sea level occurs in late winter to early spring in Southern California and at lower latitudes, whereas it occurs in late spring to summer as we go to the north of 40°N. The highest level shows a corresponding shift in its occurrence, late summer in the south and winter in the north. The component of monthly mean wind stress parallel to the coasts is computed from the statistical wind data compiled at The Scripps Institution of Oceanograpy. This shows that the maximum northerly wind occurs during March to May at latitudes between 20°N and 40°N and that it occurs during June to August at latitudes between 40°N and 60°N. The minimum northerly wind or the maximum southerly wind occurs during September to October at 20° to 30°N and it occurs during December to January at latitudes to the north of 35°N. The amplitudes of annual variations in the wind stress component are 0.1 to 0.4 dynes. cm^{-2} to the south of 40°N, and they are 0.5 to 1.0 dynes. cm^{-2} to the north of 40°N. The recorded sea level also appears to show the amplitudes of annual variations in amount of about 10 cm to the north of 40°N whereas only 5 cm at latitudes somewhat lower.

The above two independent types of data seem to suggest that the observed annual oscillations in mean sea level for these areas are caused by the annual variations in the winds. As the followings will show, the mechanism seems to be given by the dynamical process which is contained in the present theory. In all cases of our concern, it is proved that the surface deviation, z_0, taken positively downward, is given with sufficient accuracy by

$$z_0 = -h\Delta\rho$$

At the coast, the amplitude is

$$|z_0|_0 = \frac{|\tau_y|_0 \Delta\rho}{\sqrt{g H_1 \Delta\rho}} \frac{1}{\sqrt{\alpha^2+\sigma^2}}$$

With numerical values assumed as

$$|\tau_y|_0 = 0.5 \text{ dynes. } cm^{-2}, \quad H_1 = 5\times10^3 \text{ cm}, \quad \Delta\rho/\rho_1 = 2\times10^{-3}$$

$$\sigma = 2\times10^{-7} \text{ sec}^{-1} \quad \text{and} \quad \alpha = 10^{-6} \text{ sec}^{-1},$$

the amplitude becomes

$$|z_0| = 10 \text{ cm},$$

which is in good agreement with the observed values.

The phase difference between z_0 and $\tau_y|_0$ is given by

$$\text{Arctan } \sigma/\alpha + \text{Arctan } E\sigma$$

With the same values used for the quantities as above and as in the preceding sections, one finds

$$\tan^{-1}(\sigma/\alpha) = \tan^{-1}(0.2) = 2\pi\times(1/31)$$

$$\tan^{-1}(E\sigma)=\tan^{-1}(1/50)=2\pi\times(1/314)$$

Hence the phase lag for the annual variations is only 12 days or about two weeks, indicating that the phase difference can be ignored in practice. This appears also to be in agreement with the actual features. Assuming the value for α which differs from this, the results are not in accord with the actual conditions for $|z_0|$ as well as for phase difference. For instance, the same numerical values except for $\alpha=0$ yield

$$|z_0|=50 \text{ cm}$$

$$\tan^{-1}(\sigma/\alpha)=\pi/2=2\pi\times 1/4$$

$$\tan^{-1}(E\sigma)=\text{Arctan}\,(1/2)=2\pi\times 1/14$$

The computed amplitude is too large, and the computed phase lag is about 4 months for the annual variations.

It is concluded, therefore, that the observed facts appear to require the lateral friction corresponding to $\alpha=10^{-6}\,\text{sec}^{-1}$, provided that the present dynamical mechanism should at all account for the variations. In other words, our interpretation for the variations may be valid, provided that we have any reasonable evidence of lateral friction represented by $\alpha=10^{-6}\,\text{sec}^{-1}$.

4. Conclusions

The northward deep current (in the northern hemisphere) which is relatively wide and uniform produces convergence due to its planetary vorticity and consequently the upward motion in the layers above. On the other hand, the northward deep current, which is narrow with a concentrated high velocity along coast at the eastern edge, may also produce convergence due to diffusion of relative vorticity. The present study shows that the coastal upwelling, the rise of thermocline toward the coast, and the northward flow below the thermocline should take place with their phase difference practically negligible. It may then be possible, for instance, that seasonal upwelling which occurs along the coast and stays more or less steadily during a few months, conuld be detected by the "vertical divergence" in the isopycnic surfaces against the coast, that is, by the presence of deep (geostrophic) poleward flow and of a rise of thermocline near the coast. The assumed magnitude for α, representing mixing effects, which plays an essential role on the results, is discussed on the basis of various other sources of information. The validity of the assumed form of mixing might be in doubt, and α might better be interpreted to include the vertical mixing effect as well as the lateral mixing. The results of the present analysis apply readily to the eastern edge of the oceans in the northern hemisphere. However, the role of Coriolis change, β, is not important

for this dynamical system, so that the results will equally be applicable to the coastal waters in any other portions of the oceans.

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Observations along the Southern Coast of Izu Peninsula, Shizuoka Prefecture, Japan

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1. Introduction

During the latter part of February to the middle part of March 1956, observations were made along the southern coast of Izu Peninsula, Shizuoka Prefecture, with the purpose to investigate the general features of the coastal area, distribution of the molluscan fauna, and the possibility for the establishment of new culture grounds for edible shell-fish.

The area where observations were made stretches from Itado in Shirahama-mura on the eastern side of the peninsula, southwards to the Iro Light House in Minamisaki-mura via Shimoda-machi, and from Matsuzaki-machi northwards to Arari-mura on the western side. The former mentioned area faces Sagami Bay, the latter Suruga Bay, and the intermediate area faces the Totomi-nada.

Dredge operations and other oceanographical observations were undertaken only in the area between Minato in Minami-izu-machi and Shimoda Bay along the southern coast owing to the prevailing winds making further work difficult. Bottom sediments were collected from the area just mentioned and also from Arari Bay in Arari-mura on the western coast of the peninsula. In the latter mentioned bay the sediments were collected by a Seki-type bottom sampler. A plankton net was hauled several times at the mouth of Shimoda and Nabeta Bays. Since meteorological and oceanographical observations are continually recorded and published by the Shimoda Marine Biological Station of the Tokyo University of Education, reference was made therefrom.

The marine fauna collected from the beaches and by dredge operation and the bottom sampler were mostly identified by the senior writer, while the Foraminifera obtained from Arari Bay was studied by Mr. Hiroshi Ujiie of the Geological and Mineralogical Institute, Tokyo University of Education. All photographs included in this article were taken by the writers.

2. Acknowledgements

For the opportunity to use the facilities of the Shimoda Marine Biological Station at Nabeta Bay, Shimoda-machi, deep appreciation is due to Professor Shunichi Takatsuki, Director and Assist. Professor Isokichi Harada and other staff

members of the Station. Thanks are due to Mr. Buei ARAYA of the Japan Society for Promotion of Science for making the necessary arrangements with regard to the present project. Acknowledgements are due to Mr. Hiroshi UJIIE of the Tokyo University of Education for kindly identifying the Foraminifera procured by the bottom sampler from Arari Bay.

3. The Southern Coast of Izu Peninsula

The coast line of the southern tip of Izu Peninsula from Hamazaki-mura at the east to the Iro Light House at the west is indented with many narrow inlets and coves, with only three bays worthy of mention (Shimoda, Minato and Nabeta), several narrowly projecting promontories, and numerous small islets of various sizes and shapes bordering the coast. Sharp cliffs are found where sand or gravel beaches are not developed. This coastal topograpy represents one of submergence.

The eastern coast extending from Itado in Shirahama-mura to the tip of the peninsula, has very few indentations and noteworthy is the sand beach of Shirahama and Sotoura. Both of these beaches are built of sand derived from the adjacent Miocene Shirahama formation. The sand of the two beaches seem to be only a thin covering as is inferred from the exposures of the bed-rock around and in the beaches. The sand itself seems to be protected from aqueous transportation by the direction of the prevailing winds and to that the boulder to cobble zone below and at the strand line serves as an obstruction.

The western coast from Arari Bay at the north to Matsuzaki-machi at the south has several large but very few or small identations, the larger bays are those of Arari, Otago, Nishina and Matsuzaki. Small islets are found along the coast from Nishina-mura to Otago Bay. Only the beaches of Matsuzaki and Nishina are worthy of mention. Sharp sea cliffs are rather common along the western coast so far as observed.

From the topographical features of the area above mentioned it is interesting to notice that the southern tip of the peninsula presents features which suggest submergence more strongly than of the eastern and western sides, thus appearing as if differential movement would be necessary to produce such contrasting aspects. Although the southern tip presents such features it is also evident that recent emergence has produced some modifications. Favoring the aforementioned view is the difference in the valley systems, those of the southern tip are directed southwards while those farther north are east-west in trend; the former having more abrupt entrances than those of the latter.

The features of the coast line together with the evidence to be given for the

recent change in sea level apparently have direct bearing on the possibility of shell-fish culture and on the population of the fauna living there. As other evidence for change in sea-level may be mentioned the well developed sea caves of considerable extension of Dogashima in Nishina-mura and Osada in Shirahama-mura, where the side-walls of tuffaceous sandstone extend several meters under-water.

Benches abraded to various degrees are rather well developed along the southern coast and around some of the numerous islets above mentioned. These benches vary in their width and extension along the coast and in development around the islets. Some of the islets show evidence of changing into a tombolo by the landward and seaward growths of the sediments owing to the obstructions. The most typical example is seen between Nishina-mura and Tago-mura on the west coast. Those on the southern coast are miniature and premature compared with the one just mentioned.

The benches at or near sea-level during high tide have their surfaces rather irregular owing to the cobble to boulder size andesite blocks in the agglomerate being removed by wave action. However, their development is better seawards than landwards along a small promontory. The height of the benches on the small islets correspond to the notches developed in the sea cliffs particularly of the indented areas. The former appear to have their surface gently inclined landwards, the angle of which correlates with the position of the large notches just mentioned. This gives the impression of landward tilting. It is further inferred that the large notches are due to the lowering of sea-level, the view being interpreted from the large oblique angle of the notch in profile and to the degree to which it has been incised as well as to its position. Whether the growth of the above mentioned tombolos is due to mere deposition of waste material or to deposition assisted by the lowering of the sea-level is a problem for further study.

Landward tilting of the southern tip of the peninsula due to the Izu earthquake of November, 1930, may be one of the reasons for the slight landward inclination of the benches fringing the small islets along the coast. This emergence may also be related with the rapid erosion of the sea-cliffs bordering the southern tip of the peninsula, which has resulted in the production of cobble to boulder beaches and helps to explain the scarcity of sand beaches, along that coast.

Pot-holes are well developed along the southern coast, and on the southern side of Doga-shima islet in Nishina Bay on the west coast, and on the coast of Harada, Shirahama-mura on the eastern side of the peninsula. The marine pot-holes are of interest in their arrangement, size, and shape as well as positions on the coast. Being marine in origin their development may be different somewhat from those commonly found in streams. Some appear to be in the process of destruction and others in that of construction.

Among the varied types of pot-holes the large one found at the base of a well

developed notch between Minato and Toji in Asahi-mura on the south coast is of interest from its developmental process. This pot-hole is nearly circular in outline, measuring about 1.5 meters in length and width and about 70 centimeters in depth. The sides are quite vertical or very slightly convex, abruptly curve into the rather flat or bowl shaped bottom. In the hole was found sand, granules, pebbles and several boulders of which only one was well rounded, the others had angular sides, probably they were thrown into the hole by wave action or directly derived from the agglomerate cliff into which the notch and pot-hole are incised.

The notch and pot-hole are incised in andesite agglomerate tuff. In the cove where the notch and pot-hole occur there are found numerous well rounded boulders of andesite lying directly upon the bedrock just mentioned. This large pot-hole may have been formed by the assistance of several andesite rocks rather than by a single one, and the pebbles may be remnants of larger rocks which joined in the abrading of the bed-rock simultaneous with the development of the notch itself. Regardless of the details in process of development of the pot-hole it is worthy of notice that such can develop at that base of a notch. It is thought that the developmental process of the notch and pot-hole were simultaneous, wave action taking place in the formation of the former and the derived materials being utilized in the abrading of the latter.

On the coast of Toji above mentioned there were found pot-holes in andesite. The andesite appear as boulders at places and on a part of the same beach it occurs as a flow, partially covered by Miocene sediments. Therefore, it is thought that the apparent boulders are really a part of the eroded surface of the andesite flow, which was partially covered with subsequently deposited sands. From the outcrops of the Miocene sediments and andesite flow it is inferred that the beach sand here is merely a thin covering. Another reason for upholding the view that the andesite boulders separated from one another on a part of the beach represent protruding parts of the very irregular bed-rock of andesite is because the majority of them are incised with partially destroyed pot-holes, all of which show normal orientation. These apparent boulders are not covered during normal high tide and their surfaces are highly polished, probably by wind abrasion. Judging from the measurements of the partially destroyed pot-holes, many of them were originally about or more than 40–50 centimeters in depth and about as much as wide. However, at present, except for a part of their sides, all have been removed by erosion. None retain their original shape. Some have only their bottom preserved as a saucer, others as an incomplete bowl, still others with one half missing, and some appear as a shallow half-cut dumb-bell. All appear to have been modified by subsequent aqueous and aeolian agents. This kind of pot-hole is not common so far as the writers observations are concerned.

On the rocky beach at Ose between the Iro Light House and Shitaru in Minami-

izu-machi there are several types of marine pot-holes which are developed at different heights above sea-level. These developed at sea-level are circular, ovoid, dumb-bell shaped, elongated or a series of connected ones. Their sizes vary from several to about 40 centimeters in depth, from about 15 to 50 centimeters in diameters, according to their state of construction or destruction. None of the circular or ovoid shapes ones contained material suggesting them to be tools of abrasion. Even the elongate or serially connected ones had no such materials in their bottoms. The absence of such tools may be due their removal by wave action, which probably also was responsible for supplying new ones. These have their longer axis arranged nearly at right angles to the approaching waves.

Adjacent to these pot-holes just mentioned, there was found another of larger size and about one meter higher above sea-level. This one measured about 1.90 meters in maximum diameter, 85 centimeters in shorter diameter and 130 centimeters in approximate depth and is connected with another which measured one meter in longer and 60 centimeters in shorter diameters and about 60 centimeters in depth. In the larger one there was incised in its bottom another of smaller dimensions, being about 30 centimeters in both diameters, and about 15 centimeters in depth. These two large pot-holes may not have been made at the time those situated one meter lower were built, but probably at a slightly earlier date, when the sea-level was higher than at present. It is also thought that even though storm waves may have considerable effect on the coast, their duration may not have been sufficient for the production of the higher pot-holes.

The coast of the southern tip of the peninsula where sand or gravel beaches do not exist, boulders and cobbles are outstanding. Where such rocks are common, numerous islets are found off the coast and generally cliffs occur at or very close to the strand line. The same conditions may be seen between Takashima islet and Kameko-iwa islet in Nishina-mura on the west coast.

The beach on the northern side of the Nishina River in Nishina-mura consists of pebbles in its southern half which form a narrow zone along the strand line, but of sand on the landward side. The size and quantity of the pebbles becomes smaller and less towards the middle part and grade into sand at the middle northern part of the beach, and thus continue throughout its remaining length. Thus demonstrating the direction and ability of the transporting agents.

From the evidence so far presented and from the fact that beach collecting and dredge operation failed to reveal abundant specimens of the two common edible clams, *Tapes japonica* Deshayes and *Meretrix lusoria* (Röding) as well as those belonging to *Anadara*, at least in the southern half of the Izu Peninsula, it can be said that the prevailing conditions are not favorable for their growth. Also from the fact that the beaches are only thinly covered with sand which may not be stable, that cobbles and boulders befront the extensively developed sea-cliffs, that

silty-sand beaches are lacking, and from the prevailing winds which cause aggitation of the shallow waters near the strand line, it is inferred that the conditions are unfavorable for the establishment of new culture grounds for the above mentioned shell-fish.

Although living oysters are extremely abundant at places along the southern half of the peninsula, it is also evident that their culture cannot be done by the raft-method because of strong winds and waves. Thus with regard to the oysters it is suggested that connecting anchored bouys with rope or wire with short, spat-attaching apparatus, tied to them, may be a probable method.

As to edible shells belonging to *Turbo* and *Haliotis*, it is suggested that regulations for their harvest be made to unify the production and to retain the industry.

With regard to the distribution of the shell-bearing molluscs along the southern coast of Izu Peninsula, and their further extension both northwards and southwards of the peninsula, another article will be devoted. This report is the first of the few that are expected to be written with concern to the observations made along the southern coast of Izu Peninsula, Shizuoka Prefecture.

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Explanation to Plate

Fig. 1: Tombolo of Takashima, viewed from the mainland. Nishina-mura, Kamo-gun, Izu Peninsula. The photograph was taken during high tide. The tombolo is almost completely exposed during lowest low tide.

Fig. 2: Islets and benches offing the promontory at Ose, Minami-izu-machi, Kamo-gun, Izu Peninsula. Note the cobble and boulder beach in the foreground.

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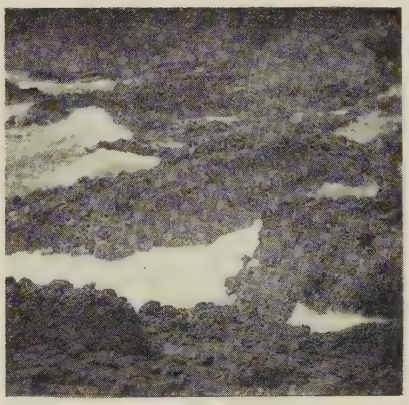

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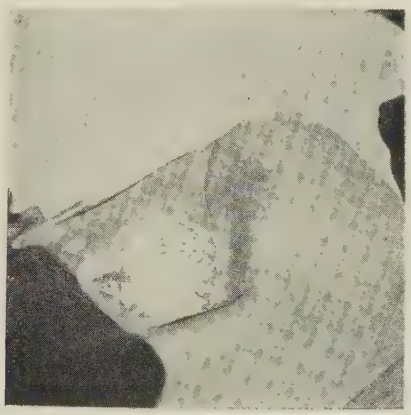

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Fig. 3: Coast of Nabeta Bay looking south. Shimoda-machi, Izu peninsula.
Fig. 4: Coast of Itado, Shirahama-mura on the east coast of the peninsula. Note the rough surface of the bench.
Fig. 5: Pot-hole at the base of a large notch. Between Minato and Toji in Asahi-mura, Kamo-gun, A few boulders and cobbles can be seen inside the pot-hole.
Fig. 6: Eroded pot-hole incised in andesite on the beach of Toji, Asahi-mura, Kamo-gun. Such apparent boulders are scattered on a part of the sand beach.

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Preliminary Observations along the Sea Coast of Wakayama Prefecture, Japan

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1. Introduction

During the latter part of December 1956, observations were made along the sea coast of Wakayama Prefecture, between Kirimezaki, Kirime-mura at the north to Seto-zaki, Shirahama-machi at the south, and also along the sea coast near Kushimoto-machi at the southern tip of Kii Peninsula.

Although the present project was concerned with the bottom sediments of Tanabe Bay, Wakayama Prefecture as related with currents, tides, and waves to the country rocks, the prevailing northwest winds prevented the work. Therefore, observations were directed to the abrasion platforms, benches and raised beaches distributed along the coast of the area studied, to find whether evidence may be obtained with regard to recent changes in sea-level.

Owing to the mentioned circumstances the present article is intended to be preliminary to a more detailed one, hoped to be written after another opportunity to visit the coastal region of Wakayama Prefecture.

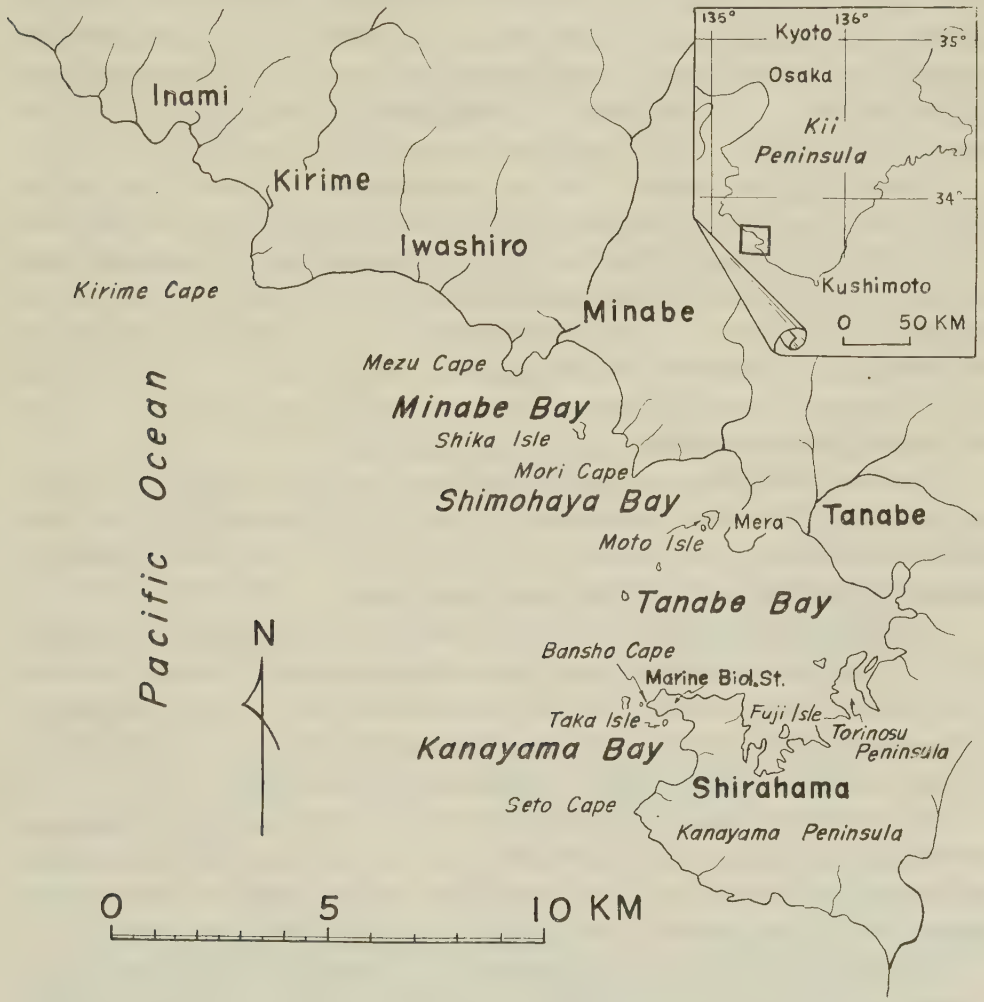
2. Acknowledgements

For the use of the facilities of the Seto Marine Biological Station of the Kyoto University at Shirahama-machi, Wakayama Prefecture, and also for the kindness received during our stay, we wish to thank Dr. Huzio Utinomi, Superintendent and other members of the Station. Acknowledgements are due to Assist. Prof. Yushi Funayama, Messrs. Tamio Kotaka, Jun Kataoka and Miss Tomoko Takeda of the Tohoku University, Sendai, for their support in many ways. To Mr. Buei Araya of the Japan Society for the Promotion of Science we express our deep gratitude for his kindness in making the necessary arrangement for the trip.

3. The West Coast of Kii Peninsula

The west coast of Kii Peninsula between Kirime-zaki, Kirime-mura at the north and Seto-zaki, Shirahama-machi at the south is characterized by the irregular southeast to southwestly curved coast line, occupied with four bays of different sizes but of more or less rhythmic arrangement and different shapes. These are, enumerated from the north, Minabe, Shimohaya, Tanabe and Kanayama Bays.

Minabe Bay consists of sand derived from the unknown Mesozoic country rocks and is rather sharply convex landwards, being limited at its northern side by the small promontory of Mezu-zaki and at its southern part by the cape of Ueda-zaki. Only a small detached abrasion platform is found near the southern part of the bay. The islet of Shikajima off shore has two rather flat levels, the higher corresponds to the benches developed on the mainland, and the lower to the abrasion platforms extensively developed along the coast.



Text-fig. 1. Index-map showing the localities of the more important names referred to in this article.

Between Minabe and Shimohaya Bays there are developed three small capes, nearly equi-spaced, and named from the north they are, Ueda-zaki, and Morihana with an unnamed one between. The one of Morihana is largest and preserves a

raised beach deposit. The deposit consists largely of medium grained yellowish sands with rusty-brown pebbles and cobbles of mudstone and sandstone at the base, and shells and fragmental coral stocks were sporadically distributed throughout the sand.

Shimohaya Bay is more or less of quadrate form with the sand beach distributed as a narrow zone and befronted with abrasion platforms. At the southern part of the Bay is the islet of Motojima, which has well developed abrasion platforms and benches fringing it. The large promontory of Mera which limits the southern part of the Bay, has besides the well developed abrasion platforms and benches, good development of raised beach deposits which yield numerous corals and marine shells. Its distribution is rather extensive being known from both sides of the promontory, which separates Shimohaya from Tanabe Bay.

Tanabe Bay is the largest of the four mentioned and is limited at its northern side by the promontory of Mera and at its southern part by the small peninsula of Seto on which is situated the Seto Marine Biological Station. Numerous islets as Kami-jima, Fuji-shima, Hana-jima and many unnamed ones are found in the southern half of the bay, where abrasion platforms and benches are exceedingly well developed. Raised beach deposits also occur sporadically as at the northern and northwestern parts of Torinosu peninsula, and on the northern coast of the Seto Marine Biological Station.

The abrasion platforms and benches developed nearly throughout the southern half of the bay are built of conglomerate or sandstone of Miocene age, and with regard to sea-level it is interesting to notice that all do not show the same relationship, some being more or less higher than others.

The southern coast of the bay is richly indented with many small and narrow inlets or coves, and presents a typical submergence topography, in strong constrast to the gently curved coast from Minabe Bay to Kirime-zaki in the northern part of the observed area. Further, numerous submerged platforms or shoals exist on the seaward sides of the mentioned exposed abrasion platforms.

These submerged shoals or platforms extend from near Kami-jima islet in the southeast part of Tanabe Bay eastwards to off cape Bansho-no-zaki to the southwest part of the same cape. Their distribution is well displayed in the photographs taken by an air-plane of the Yomiuri News Paper Branch of Osaka City.

Kanayama Bay with the small promontory of Gogenzaki at its middle part is delimited by the cape of Bansho-no-zaki at the north and that of Saki-no-yu at its southern part. Sand beaches occur only near the Seto Marine Biological Station and the sea-front of the Shirahama Spa, elsewhere the bed rocks of Miocene age outcrop.

From Saki-no-yu to the cape of Seto-zaki only the bed rocks of Miocene age are exposed and along the coast are developed some benches of different heights

and rather narrow abrasion platforms.

4. Raised Beach Deposits

As already mentioned in the foregoing lines, raised beach deposits are developed sporadically along the coast. These deposits are all characterized by consisting of medium to coarse grained, unconsolidated sand, yellowish in color, and generally with well water worn, rusty-brown colored pebble to cobbles of sandstone, siltstone and tuff at the base. Reef corals are generally found in the lower part of the deposit intermingled with gastropods and pelecypods, while in the upper part corals are not found and the marine shells become less numerous. Cross-bedding of the sand or gravels composing the deposit is not extensive and was noticed only at several localities as on the northern coast of the Shirahama Marine Biological Station and along the coast of Iwashiro between Kirime-zaki and Mezu-zaki.

As to the height of the base of the raised beach deposits above or below sea-level, and that of the uppermost, taking the normal high tide as the standard, the following Table 1 shows the approximate measurements.

Table 1

Showing minimum and maximum heights of the raised beach deposits with regard to normal high tide.

Localities	Minimum	Maximum	Remarks
Iwashiro, Minabe-machi	0 m	9 m	No reef corals, fragmentary shells
Morihana, Minabe-machi	50 cm	2 m	Reef corals and shells, common
Mera, Tanabe City	−10 cm	2.50 m	Reef corals and shells, common
Torinosu, Tanabe City	−30 cm	10 m	Reef corals few, shells common
	−30 cm	3 m	Reef corals and shells, few
Tsunafuchi, Shirahama-machi	?	2.50 m	Fragmentary corals and shells
Ezura, Shirahama-machi	0 m	2 m	Reef corals and shells, few
North coast Marine Sta.	0.5 m	7 m	Shells, sporadic
Residency of Marine Sta.	?	10 m	Shells, sporadic
Kushimoto-machi	0 m	1.5 m	Reef corals and shells, common

From the above data it is inferred that there was, to some extent, considering either the position of the base or of the uppermost part of the raised beach deposits with regard to sea-level, crustal movement, which may have been due to block movement, warping or to some other phenomena. Whatever be the cause, it appears as if there was local movement, even though the dip of the deposits could not be measured at the time of observations. Whether the movement resulting in the difference of the heights of the base or uppermost parts of the

raised beach deposits has bearing on the development and arrangements of the abrasion platforms and benches remains to be settled. Further, their relation with the extensive marine terraces distributed along the west coast is also of importance.

5. Abrasion Platforms and Benches

Abrasion platforms are distributed along the coastal area observed and are well developed on the seaward sides of promontories or capes and in the southern half of Tanabe Bay. These platforms present several distinctive features in their arrangement and shapes.

Several types of cross-sections can be recognized as, those which have abruptly terminating margins, those with the margins sloping at angles less than 45 degrees, those which have one side abrupt and the other sloping, and those which have abrupt margins but with a shallow notch. Those consisting of conglomerate or alternating layers of siltstone and sandstone, of siltstone and tuffaceous material, all of Miocene age and low dips, possess many characteristics in-common. Of the abrasion platforms built of such material, several types are noticed, such as, those which have flat or nearly flat surface extending to the shore, cliff or promontories, those which have their portions near the land gradually raised, those in which small tide pools are developed, those in which small and narrow crevices or channels are penetrated and continuously being effected by the attack of waves. Other types although not so distinct are those that appear to be tilted or inclined to a very small degree.

As to their seaward extension or width, considerable variation can be seen, some being larger and better developed than others. From air photographs it is also evident that there are numerous submerged platforms or platform-like shoals continuous with the exposed abrasion platforms in some cases and apparently detached in others. These will be treated at another opportunity.

Of particular interest are the several abrasion platforms befronting the sea cliff of and southwards of Kirime-zaki in the northern part of the area observed. Here the five platforms all consist of alternating layers of overturned and highly inclined sandstone and siltstone of unknown Mesozoic age. The siltstone layers have been largely removed by erosion and the sandstone layers form sharp, variously curved by folding parallel ridges owing to their strong resistance against weathering and erosion. These platforms are each convex seawards with uniformly arranged outer margins, arranged in rhythmic pattern, with rounded apices, separated by rather narrowly v-shaped valleys, and their height above sea-level differs from west to east direction, being higher in the former and gradually becoming lower towards the latter. The westernmost is fully exposed above normal low tide, and the easternmost is submerged, and the ones in-between are

intermediate in characters.

These abrasion platforms are probably best considered to be products of simultaneous wave action. They are built of the same material and expose no recognizable fault between them, even though their present positions above sea level are not the same. Thus, it is inferred that downwarping relative to upwarping may have been responsible for bringing some of the abrasion platforms below low tide level and others above the same level. However, since no faults were recognized, block movement does not seem to have been the cause.

As already mentioned the types which appear, though not so distinct, to be tilted or inclined to a very small degree, and those of the other types referred to, all seem to show or at least suggest that some crustal movement has taken place since the formation of the abrasion platforms. Also the characters of the platform margins, and presence of shallow incipient notches on the faces of some of the abruptly terminating platforms margins may also have bearing on the problem of crustal movement. It may also be added here that some of the abrasion platforms preserve mushroom rocks eroded to various degrees on their flat surfaces. The general height of their surfaces roughly corresponds to that of the benches developed along the mainland.

Benches are developed sporadically on the islets, cliff fronts and are distributed nearly throughout the observed area, although their density varies with places. These are generally narrow, measuring about several to some ten meters in seaward extension, and varying in height from about 1.5 meters in the vicinity of the Mera promontory, 2 meters along the cliffs of Seto-zaki, and to about 3 meters in the vicinity of Bansho-no-saki. Although precise accounts could not be taken of all of the benches owing to their being developed on small islets inacessible at the time due to the prevailing winds and waves, it is thought that all may fall within the range height just mentioned. Where the benches are high, the abrasion platforms also are high, although the bases and uppermost parts of the raised beach deposits are not in accord.

Where high level benches occur as on the northern side of the Seto Marine Biological Station, it is interesting to find that many sea-caves in different stages of development are incised into the sea cliff. Some of these caves, though still premature, are incised into the cliff for about five meters with heights of about two meters. Their entrances vary in shape, some appear as a semi-circle, some are laterally ovoid and others look like laterally developed slits. The last mentioned one is only about one meter high but reaches back into the cliff as much about three meters.

Also at levels corresponding to that of the high level benches are found incipient notches and other evidences of wave erosion. The same phenomena as mentioned here and above are also found in the case of the low level benches.

In one notch developed under an arch on the northern shore of the Seto Marine Biological Station, there was found a small pothole. This pothole measured 90×40 cm in diameter and about 40 cm in depth, and was filled with pebbles derived from the conglomerate into which it is incised. It is inferred that wave action dislodging the pebbles from the conglomerate and leaving a small hole there, was subjected to further dislodging and erosion with the pebble as the tool by the action of waves. This procedure lead to the final development of the pothole.

6. Marine Terraces

Marine terraces are beautifully developed, especially along the coast of Natamura in Hidaka-gun northwest of Kirime-zaki, where they are nearly horizontal, arranged in cuspate rhythmic pattern, convex seaward, and befronted with sea-cliffs which have at their bases abrasion platforms and benches.

The marine terrace of the promontory of Mezu-saki slopes slightly seaward, less sharply than the one on the promontory of Mera promontory. The terrace of Seto-zaki slopes seaward, while the one of the Seto promontory appears to be nearly flat.

The cause of the different inclinations of the marine terraces may be related to the differences observed in the positions of the benches and conditions of the abrasion platforms, and all with the changes in heights of the raised beach deposits.

It is considered that the sloping of the marine terraces sea-ward with low angles is not a phenomenon due to movement subsequent to their formation but actually represents the initial dip. However, those appearing nearly horizontal or with landward dips are believed to be due to some kind of movement subsequent to the making of the marine terrace.

In the western part of Kushimoto-machi at the southern tip of the Kii Peninsula, the marine terraces generally slope seawards with very low angles. However, the long and narrow promontory immediately west of Kushimoto-machi is nearly flat contrary to the general trend of the majority of the marine terraces.

Also interesting from the view of erosion in the northeastern part of Kushimoto-machi which is situated on a tombolo is the development of many stacks on the quite flat, low level abrasion platforms.

It may be stated that problems remain as to explanations for the cuspate rhythmic arrangement of the marine terraces, bays and abrasion platforms. Local upwarping relative to downwarping, block movement, or tilting due to dome-formation may be listed among causes leading to the production of the aforementioned phenomena. However, evidence of the last mentioned two phenomena seem to be lacking, and the first mentioned may be insufficient for explaining the total relationship of the features of the raised beach deposits, abrasion platforms, ben-

ches and marine terraces as stated in earlier pages.

As a suggestion it is thought that there may be a possibility that the relatively raised portions may represent a positive area and the relatively lowered areas a negative one, while the intervening one a more or less neutral area. If this suggestion is considered, it is thought that the differences in the heights of the abrasion platforms, benches and bases and uppermost parts of the raised beaches, and their cuspate rhythmic arrangement may be explained. In other words the said movement may have been responsible for the production of the various phenomena already referred to. However, it should be known that the erosive power of wind, tide, currents when directly attacking the coast, or when befronted with an obstacle so as to produce their refactory agencies, and the effect of long shore currents acting together with wind waves are also given consideration with regard to the present problem.

Difficulty of explanation is the cause of the initial cuspate pattern which has grown to the state now displayed along the west coast of Wakayama Prefecture. The mid-streamward dip of river terrace deposits increasing in accordance with nearness to the coast, also is an interesting unexplained problem. The rhythmic pattern of various phenomena as already described needs an explanation. Possiblly the height differences according to age may be explained by the area-shifting idea, which is thought to be of some help in interpreting such problems.

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Explanation to Plate

Fig. 1. Bench along the northern coast of the Seto Marine Biological Station, Shirahama-machi, Wakayama Prefecture. The bench is incised in conglomerate.

Fig. 2. View of a sea-cave incised into conglomerate. The sea-cave is on about the same level as the bench shown in Fig. 1. Same locality as Fig. 1.

Fig. 3. Mushroom rock on an abrasion platform off the coast of the Torinosu Peninsula, Tanabe City, Wakayama Prefecture.

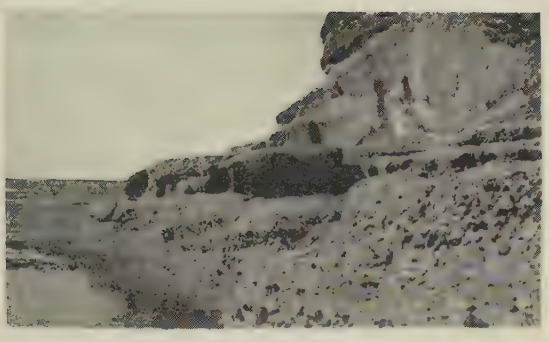
Fig. 4. Small islet on a well developed abrasion platform on the north coast of the Seto Marine Biological Station, Shirahama-machi, Wakayama Prefecture.

Fig. 5. Abrasion bench built of overturned sandstone strata of unknown Mesozoic age. The siltstone layers have been eroded away. Locality, coast of Kirime-zaki Promontory, Kirime-mura, Nishi-Muro-gun, Wakayama Prefecture.

Fig. 6. Abrasion platform in the foreground and marine stacks situated on abrasion platform in the distance. Seen from the coast of Kushimoto-machi, southern tip of the Kii Peninsula.

Fig. 7. A very deep tide-pool incised in the abrasion platform near Fujishima, Tanabe City, Wakayama Prefecture.

Fig. 8. Abrasion platform and very narrow bench situated on the small islet befronting the promontory at Motojima, Tanabe City, Wakayama Prefecture.



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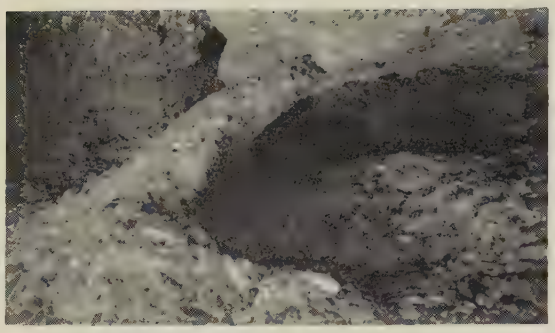

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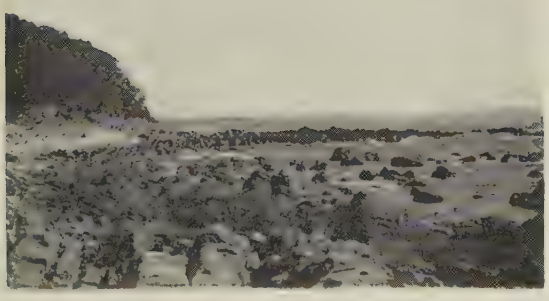

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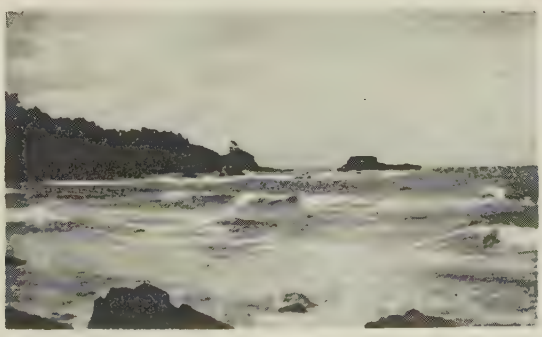

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Evidence for an Ancient Shoreline on a Marine Terrace, West Coast of Wakayama Prefecture, Japan

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1. Introduction

During observations along the west coast of Wakayama Prefecture in the latter part of December 1956, we were fortunate in finding evidence for determining the position of the ancient shoreline. The evidence as considered by us includes the gravel filled sea-cave, former sea-cliff, other kinds of holes due to marine erosion, and the features of the sediments preserved on the marine terrace. These evidences were all found on the middle part of a marine terrace profile.

In general, there are abundant literatures concerning marine terraces and also discussions with regard to ancient shorelines. However, it is regretted that the line of demarcation in the slope is generally taken to represent the position of the ancient shoreline, a view which we believe should be given more consideration from geological facts.

In this article are described the terrace deposits and surface features of the basement rocks, with the view to make clear the geological significance and process in the development of the marine terrace situated in the southwestern part of Shirahama-machi.

As may be noticed from the topographical maps of Minabe, Tanabe, and Susami, published by the Geographical Institute of Japan in the scale of 1:50,000, marine terraces are well developed along the west coast of Kii Peninsula. Although reference will be given to only one of the many marine terraces, it may be added that a study of them may produce results similar to that described in this article.

2. Observations

The cape of Seto-zaki situated in the southwestern part of Shirahama-machi, Nishi-Muro-gun, Wakayama Prefecture, is a broad marine terrace extending over 350 meters in maximum width and measures between 15 to 30 meters above sea-level. It is built of alternating strata of sandstone and siltstone of Miocene age. These strata slope sea-wards with an angle of about ten degrees in maximum and are faced with steep sea-cliffs on their northwest, west and southwest sides. The angle of inclination of the terrace is seven degrees in maximum and is accordance with the shape, sloping northwestwards, westwards, and southwestwards, respec-

tively. This structure apparently suggests a dome-structure of the foundation rocks subsequent to the formation of the terrace.

The seaward area of the terrace is not covered with any deposits, but as one proceeds landwards, the development of boulders measuring as much as three meters in diameter, and cobbles strewn on its surface becomes outstanding. Further inland the angular to rounded rocks just mentioned gradually change to cobble to pebble size materials and their degree of roundness increases. Still advancing landwards the pebble size rocks predominate and cobble size ones become rather rare. These pebble size gravels admixed with coarse-grained sand comprise the chief deposits of the terrace and have extensive distribution along the coast.

The exposures along the road traversing the terrace exhibit several important features. As shown in the accompanying photographs, at one place the terrace gravels were found filling rather deep excavations in the Tertiary rocks, appearing as if filling pot-holes incised into the foundation rocks during the stage of terrace development. Near the pot-hole like excavation, the terrace gravels overlie the foundation rocks with very irregular surface, forming at places pocket-like fillings. The same outcrop presents several lens-like structures, namely, the terrace gravels appear to be embedded, lens-like, in the Tertiary strata. However, close examination shows that these structures are not syngenetic in origin, but epigenetic. The gravels are thought to have been deposited in notches or sea-caves incised into the sea-cliff, and therefore, do not belong to the Tertiary sedimentaries in age.

At another outcrop near the one just mentioned, there was found a rather large lens-like structure surrounded with Tertiary sediments, giving the impression of its syngenetic origin. The material composing the lens-like structure agrees with the Terraces deposits and the orientation of them do not agree or appear to be in harmony with the deposition of the Tertiary sedimentaries. Further, by digging out parts of the lens-like forming gravels, it was found that none of them intergrade with the Tertiary sediments, all form sharp contacts therewith, ferrous oxide is deposited and coats the boundary between the lens-like gravels and surrounding Miocene sandstone; the degree of consolidation of the two are dissimilar, that of the gravels being loose that of the sandstone more or less indurated. Thus, there is an unconformity separating the two deposits.

Although it is accepted that the excavations which received the gravels to produce lens-like aspect was made during the age of terrace formation, it is also considered upon the aforementioned evidence, that the material filling the holes do not belong in age to that of the Tertiary sediments. The observed outcrops show the same features.

The origin of the excavations in which the lens-like arranged gravels were deposited is considered to have been a sea-cave or less probably a notch deeply incised, of which only a portion is now preserved. Such phenomenon are common

along present sea coasts just above high tide line.

It is important to state that the general contour of the excavations is more or less parallel with the bedding plane of the Tertiary sedimentaries. This orientation is the most favorable condition for the development of present day sea-caves and deep notches. Analogous phenomenon can be observed along the present sea coast of Wakayama Prefecture. With regard to the graval filled pot-hole like structure, it may be added that similar structures can be observed along the present day sea-coasts. However, whether the original hole was a pot-hole, solution basin, eroded and enlarged crevice, small tide pool, or due to some other case is at present not clear.

The height of the ancient sea-cliff preserving the above mentioned features probably reaches to more than two meters in maximum. The terrace surface slopes uniformly seawards without any break because the ancient cliff is wholly buried by gravels, but partially observed in the road cut traversing the terrace. Here the ancient shoreline is about 25 meters above sea-level.

From the position where the ancient sea-cliff is buried by pebbles and coarse grained sand, the sediments gradually change again to cobble and pebble size gravels, but their degree of roundness remarkably decreases. Finally these sediments in landward direction merge into angular boulders which comprise the talus deposits.

3. Preservation of the Ancient Sea-cliff

It is certain that the sea-cliff, sea-caves and other features have been preserved by the subsequent deposition of beach gravels, which must have protected them from wave attack and subaerial denudation.

With regard to such deposition two different processes may be introduced, as follows. (1) Submergence of the land continued intermittently and assisted with beach drifting, gravels were being deposited. At the same time the new foot of the sea-cliff situated above the former nip had begun to be eroded by waves, and the sea-cliff retreated until reaching an equilibrium. As a result of this process it becomes evident that the landward area of the terrace is younger than that of the seaward one bordered by the buried sea-cliff. (2) Intermittent emergence developed the sea-cliff through retreat of it, since the wide terrace was formed perfectly. Subsequently as the area submerged gravels were deposited, and in this case beach drifting may have also assisted to increase the amount deposited. Thus, the landward area is older than the seaward area bordered by the buried sea-cliff.

On the other hand, it is necessary to inquire into the condition how the sea-cliff was preserved. Although it is evident that subsequent deposition due to submergence, if the sea-cliff submerges into water without any particular condition, its surface will be strongly eroded by breaker waves, because the position of the

submerged cliff may be most favorable for them. Thus the cliff will become a distinct scarp in spite of deposition.

Longshore drifting is probably favorable for deposition, and it may be noticed that a cobble to boulder zone is developed in front of the buried sea-cliff. Namely, this boulder zone might play an important role in the preservation of the cliff because the zone is considered to protect a submerged cliff from wave attack. On a marine terrace developed near Sakiyu near the terrace in question, such a boulder zone is not found, however, the distinct topographical break corresponds with the mentioned buried sea-cliff, and it is considered that such a distinct scarp must have been eroded by subsequent breaker waves and weathering. This relation may be good evidence that the boulder zone in front of the buried cliff had probably been deposited during the cliff retreat before the cliff was buried by the gravels.

Again the question of process arises. If the terrace had been formed under the second process, the boulders would result from the retreat of the very low sea-cliff which measures only a little more than two meters in height. It may be difficult to consider that such a low cliff could provide the large boulders in great quantities. Production of them may be possible, if the former terrace before the cliff retreat had been covered with the boulders, or if numerous marine stacks had developed on its surface. However, in this case the former terrace must have already reached the profile of equilibrium. So it is inferred that there were no stacks and further, the boulders should be more rounded. Although the top surface of the boulders found on the terrace in front of the buried sea-cliff are more or less round, their degree of roundness seems to have been due to both wave attack and subaerial weathering for their most part, because their basal parts often preserve the original angular surface and honeycomb structures are considerably developed on the top surface.

From the above mentioned impossibilities we choose the first process for the formation of the marine terrace. In this process the boulders would be easily supplied in abundance because the sea-cliff had been high enough for the rich supply. Therefore, according to the first view of the process the following explanation is given to the marine terrace of Seto-zaki, and it is also thought that other marine terraces developed along the coast of Wakayama Prefecture may be explained in the same way, even though local movements subsequent to their formation may have exerted some influence with regard to their modification.

4. Process of Formation

The first stage of marine transgression leading to erosion of the general land surface and deposition of coarse clastics as the sea advanced, finally reached a position where active cliff-making commenced. Owing to the temporary neutral sea-level erosion proceeded in incising the sea-cliff to produce sea-caves, possibly of

various depths and of different shapes. During this time deposition reached a condition exceeding that of erosion, whereby abundant shingles or gravels fringed the sea-cliffs. However, there was developed a cobble to boulder zone, beyond which sand again predominated.

Continued submergence of the land and possibly assisted with longshore currents gravels were being deposited in abundance. As the gravels were being supplied and the water-front advanced landwards, probably to near the position where a sharp break occurs in the present day topography. This sharp break in topography does not represent the shoreline at that time, but the foot of the talus zone then flanking the lower parts of the highland. The original shoreline is thought to have been considerably in front of this talus zone as is judged from the distribution of the gravels and its relation with the talus boulders now covered with soil. At this stage of sea-level the profile of equilibrium is judged to have been so as to completely cover the previously constructed sea-caves. Gravels and other deposits are considered to have extended at least to the margin of the marine terrace.

The next phase in the history commenced with regression of the sea which is considered to have been gradual at least to the height of the terrace margin. By this regression, the primarily deposited materials were rapidly eroded and almost completely removed from the seaward part of the terrace. Thus at present the seaward part is bare with only scattered gravels in front of the rubble zone, back of which there are better developed gravels. These gravels gradually rise in height landwards and although incised by the road cutting their top apparently grades into the terrace deposits, which are about a few meters in thickness. These covering gravels extend landwards to near the sharp break in the topographical features, which consists of talus deposits already referred to.

The next or second stage in regression is thought to have been rather abrupt from the occurrences of benches below the terrace margin and the third phase was more gradual and resulted in the construction of the shore abrasion platform.

Finally it is emphasized that, topographical breaks in the physiography near the marine terraces do not always indicate the position of the ancient shoreline and caution should be taken when treating the problem, apparant gravel-lens or other structures especially when developed near marine terraces should be given full consideration, present day features of sea coasts are worthy of detail observations, preservation of shoreline deposits and various structures becomes possible when the cycle of erosion is incomplete, and the study of ancient shorelines is a problem waiting further development.

5. Acknowledgements

Here we wish to express our thanks to Dr. Huzio Utinomi, Superintendent of the Seto Marine Biological Station of the Kyoto University at Shirahama-machi,

Nishi-Muro-gun, Wakayama Prefecture, for his kindness in many ways during our stay at the Station. Thanks are due to Mr. Buei ARAYA of the Japan Society for the Promotion of Science for his support in many ways. Acknowledgements are also due to Miss Tomoko TAKEDA and Mr. Jun KATAOKA of the Tohoku University for their kind cooperation in the field.

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Explanation to Plate

Fig. 1: View of the marine terrace of cape Seto-zaki seen from the south.

Fig. 2: View of the surface of the marine terrace.

Fig. 3: An isolated boulder on the terrace surface. Note the angular bottom and rounded upper part.

Fig. 4: Gravel filled excavation in the Miocene sandstone. Outcrop of a road cut traversing the marine terrace.

Fig. 5: A large lens-like structure embedded in Miocene sandstone. Outcrop of a road cut traversing the marine terrace.

Fig. 6: Two small lens-like structures and very irregular surface of the Miocene sandstone of an outcrop of the road cut traversing the marine terrace. The lens-structures shown in Figs. 5 and 6, are not syngenetic in origin with the Miocene sandstone. They are considered to represent the innermost portions of sea-caves.

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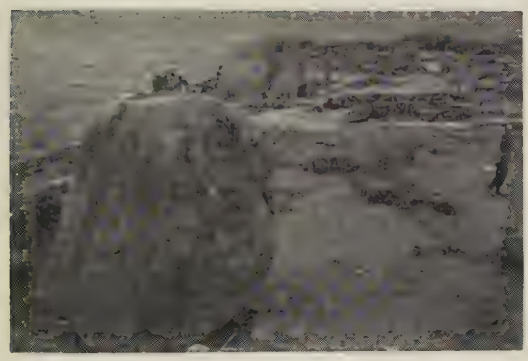

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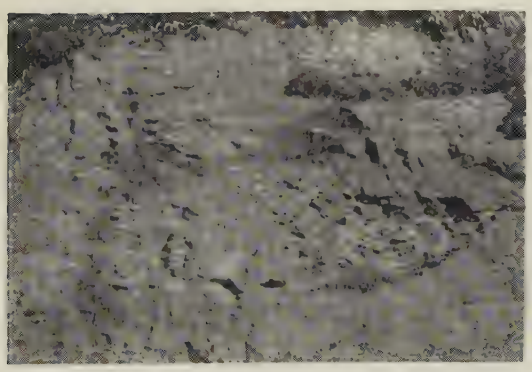

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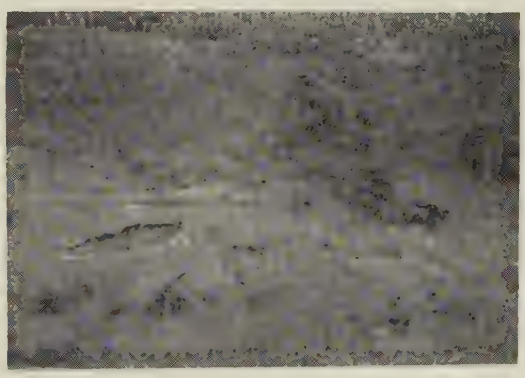

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Records of Oceanographic Works
in Japan Vol. 4, No. 1,
December 1957

A Note on the Development of Certain Marine Pot-holes along the West Coast of Wakayama Prefecture, Japan

By
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Along the sea-coast of Ezura, Shirahama-machi, Nishi-Muro-gun, Wakayama Prefecture there are developed sandstone, siltstone and conglomerates which have been referred by T. Takeyama (1930) to the Miocene age, based upon their fossil content. These different rocks build abrasion platforms, which are extensively distributed along the west coast of the Kii Peninsula, and of them, the one developed on the sea coast of Ezura above mentioned is here dealt with.

The abrasion platform to be discussed consists of sandstone bearing abundant concretions and scanty remains of ill-preserved molluscs. More interesting than the molluscs is the good development of concretions and their relation or rather rôle in the process of development of marine pot-holes or a phenomenon analogous therewith.

With regard to the process of formation of marine pot-holes, K. Tanabe (1941) has reported that, in the case of those developed on the abrasion platform of Enoshima near Kamakura, not far from Tokyo City, the ones there are developed along joints. He explains their development to be due to plucking and solution, in other words to the breaking of the columnar joints by wave action and by the broken material acting as the grinder in the place where the columnar joint was broken. Although we have not had the opportunity to study the pot-holes described by Tanabe, it is evident that his explanation can not be applied to the case observed by us.

As already mentioned abrasion platforms are well developed along the coast of Wakayama Prefecture (K. Hatai and H. Mii, in press), and at Ezura above mentioned, one of sandstone bearing abundant concretions can be seen at low tide, during which time it is almost fully exposed. On this abrasion platform besides the concretions, there can be observed round pools with bowl-shaped sides and almost rounded bottoms of various depths and sizes, tide pools, narrow and shallow channels, and also irregular shaped excavations.

Of the mentioned different kinds of excavations, the narrow and shallow channels appear to be due to various causes such as development by wave and tide action along joints and fractures in the sandstone, erosion of siltstone of the siltstone

dikes penetrating the sandstone and possibly also to erosion along penecontemporaneous faults. The irregular shaped excavations now occupied by chitons, small gastropods and sea-anemones may be due to differential erosion of the sandstone. However, the round shaped pools with bowl-shaped sides and rounded bottoms are thought to represent pot-holes which have developed through a process different from that generally accepted for those of streams.

The concretions embedded in the sandstone are exposed to different degrees, some show only a part of their top, some nearly half of their rounded bodies, others nearly the whole sphere, and still others the entire ball. Although exposed to different degrees it is important that their way of becoming exposed and released from the enclosing sandstone is due to solution, wave and tide agencies, the process being both chemical and mechanical.

Around all of the concretions observed in the sandstone it was noticed that channels are being formed, and the width and depth of them varied. Some of the channels were so deep that only a fraction of the undersurface of the concretion remained in contact with the surrounding sandstone, in some the channel was incised so completely that the concretion was completely released from the enclosing sediment, in others the concretion was nearly encircled by a shallow moat, still in others the trenching had proceeded to a depth equal to nearly half the thickness of the concretion.

From the above it is inferred that by solution the concretions are doomed to be released from their enclosing sediments, and when thus detached, a space of about one to two centimeters remained between them. This chemical releasing may not be in proportion with the degree to which the concretion is exposed above the general surface of the abrasion platform, because it was observed that some concretions with only about half of their sphere exposed above the platform were almost detached from the enclosing sediment, in other cases the spheres of some were only partially exposed above the surface but the channels encircling them were very deep.

Whether the position of the concretions with regard to the margin of the platform is related to the degree of channeling, or to its position on the platform and the strength of tides and wave action, or to the amount of water remaining on the platform during low tide, may also be important. Also the amount of water drained from the land should also be considered. Since no streams flow into this area and there was no evidence for freshwater springs issuing nearby, the role of land drained waters may be rejected from the present consideration. Since the abrasion platform is a small one both in width and length and exposed only during normal low tide and situated in the landward portion of an indented area, it appears that the degree of channeling around the concretions may not be related with their distance from the platform margin and it is considered that the influence of wave

and tide action may not be much different on different parts of the platform, because of the small size of it. Probably the amount of water remaining on the platform surface and the change in salinity by wave and tide action, the mechanical work of the wind, wave and tide with the sand grains, and the chemical reaction between the aqueous body to the concretions and consolidated silicate sediments may have been the factors governing the development of the channels.

By the above mentioned process a hole with round shape, bowl-shaped sides and round bottoms can develop without the utilization of grinding tools as in the case of those developed by streams. However, once the concretion is detached by solution and possibly assisted by mechanical action from the enclosing sediments preserving there a space of only about one or two centimeters, its movement by wave and tide action tends to enlarge the hole and decrease the diameter of the concretion. With hole enlargement and decreased diameter of the concretion, its radius of movement within the hole becomes enlarged and thus the hole grows at the sacrifice of the concretion. In some cases no concretion was found to occupy the hole.

Therefore, in the present case the holes are first made by chemical erosion assisted by the mechanical work already referred to around the concretions by means of channeling with the assistance of the obstacle which its represents. Once the concretion is detached from its enclosing sediments, wave and tide action with sand grains as the mechanical grinder, tend to facilitate its movement. This procedure leads to the enlargement of the hole and a decrease in the diameter of the concretion. Continued growth of the hole at the expense of the concretion results in the development of a hole analogous with a pot-hole in general morphological features but not in process of development. Whether this kind of hole should be referred to marine pot-hole or be given a different name to distinguish it from the common types founds in streams may be open to question.

The type of pot-hole described by K. Tanabe (1941) was ascribed to be due to the action of plucking and solution, in which sense it differs considerably from the present case. Those found in streams differ from both cases just mentioned in that the holes are scoured out of the stream beds by the action of stream flow with some kind of material as the grinder (R. R. Shrock, 1948). To understand the geological or sedimentary history of a region various features are employed, and the usage of broad terms leads to lengthly descriptions which can be simplified by the use of finner cut ones. From this view, we consider than the pot-hole described above should receive a new name to distinguish it from others having similar morphology but different process in development, although it is thought that the present one may be only a variety of pot-hole.

Finally for the present type of hole analogous in its morphology to pot-holes made by streams we wish to propose the name of obstruction-hole.

Here we wish to thank Dr. Huzio UTINOMI, Superintendent of the Seto Marine Biological Station of the Kyoto University at Shirahama-machi, Nishi-Muro-gun, Wakayama Prefecture, for his kind support during our stay at the Station. Thanks are also due to Mr. Buei ARAYA of the Japan Society for the Promotion of Science for his encouragement in many ways. We also thank Mr. Tamio KOTAKA and Miss Tomoko TAKEDA for their kind assistance in the field.

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Explanation to Plate

Figs. 1–5. Concretion-holes and concretions exposed on the abrasion platform of sandstone. Figs. 1, 2, 3, showing the channels developed around the concretions. Their width and depth vary. Fig. 4. A hole completed by solution and the concretion has become released. This free concretion may be a grinding tool in the enlargement of the hole. The name obstruction hole is here proposed for such kind of pot-hole.

Fig. 6. Solution holes in sandstone.

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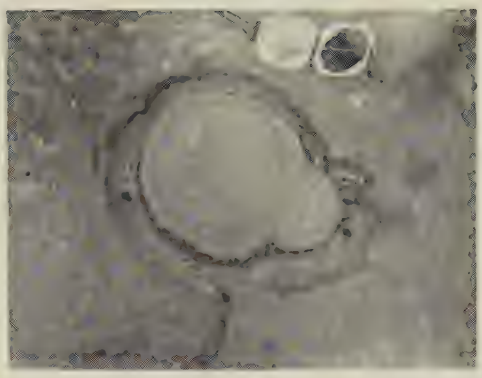

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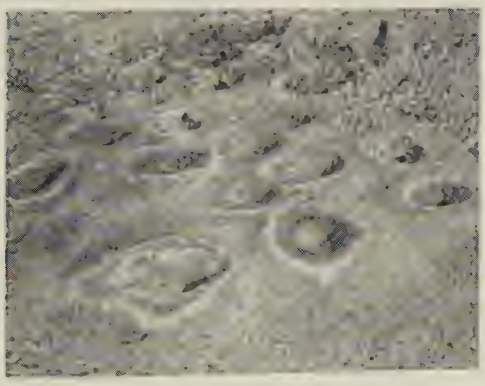

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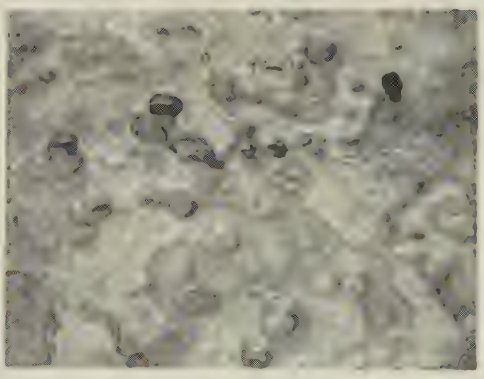

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Records of Oceanographic Works
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December 1957

A Measure on Level of Strontium-90 Concentration in Sea Water Around Japan, at the End of 1956

By
Yoshio Hiyama and Ryushi Ichikawa
(Fisheries Institute, Faculty of Agriculture, University of Tokyo)

1. Introduction

At the present level of the concentration of strontium-90 (Sr-90) in oceanic water caused by fall out of fission products by nuclear waepon tests, it is necessary to collect a huge amount of sea-water to measure its concentration by chemical analysis and radio-assay. Thus, few reliable data on it, as well as little information on proper amount of sea-water to be sampled is available to the oceanographers at present moment.

Here, the authors tried a rough measurement on the level of Sr-90 concentration of oceanic water, based upon its concentration in calcareous tissue, bone and shell, of marine organisms, through Hiyama's idea[1),2),3)] that the ratio of isotopic dilution is the same in organisms as in their environmental water.

2. Constants on Strontium Concentration

The agreeable figure for the concentration of stable strontium in oceanic water is rather constant and is 7 mg (metal) per liter as measured by Thompson and Chow[4)] and by Sugawara[5)], where 0.4 g (metal) of calcium exists per liter. So many data on concentration of stable strontium in marine organisms were obtained by Asari[6)] (precipitation method) and Thompson and Chow[4)] (frame-photometer) and others especially with regards to strontium-calcium ratio. Here, 7 mg per liter is used for the stable strontium concentration of oceanic sea water as the basis of the calculation.

3. Sr^{90} Concentration in Fish Bone

During December of 1956, the following fishes were collected from the Central Fish Market in Tokyo with some notes on fishing ground. About 100–200 g of dried bone of each samples were chemically analysed by Dr. Tamiya Asari Mr. Morito Chiba and Mr. Tadashi Ariki of the laboratory of Japan Inspection Co. on amount of stable strontium by Asari's precipitation method[7)] and radio-assayed by Dr. Fumio Yamasaki and Mr. Akira Hashizume of the Science Research Institute on the amount of Sr^{90} as shown in Table 1.

As it is reported in the author's previous papers[1),2)] that the Sr^{90} concentration in isotopic dilution ratio to the stable strontium, "Moonlight" unit ($\mu\mu c$/7 mg of stable strontium), in fish body must be the same as in environmental water, when entire turn-over was completed or equilibrium was established between the both. In these cases, no information on the degree of turn-over is available. However,

Table 1.

Fish name	Locality Caught. (Approx. depth)	Sr^{90} $\mu\mu c$ per 1g of Ca in fish bone	Sr^{90} $\mu\mu c$ per 7mg of Sr in fish bone	Sr^{90} $\mu\mu c$ per 1 liter of Sea-Water
Croaker (*Sciaena* sp.)	East China Sea (50 m)	0.11 ±0.078	$0._1$	$0._1$
Horse mackerel (*Trachurus japonicus*)	Japan Sea, off Shimane, (5 m)	0.38 ±0.04	0.6_4	0.6_4
Alaskan polluk (*Theragra chalcogramma*)	North Pacific, off Hokkaido, (15 m)	0.19 ±0.080	0.2_3	0.2_3
Spiny eel (*Dinoguellus grigorejewi*)	North Pacific, off Hokkaido, (50 m)	0.028±0.028	0.0_3	0.0_3
Blue shark (*Goleus glaucus*)	Mid Pacific (Surface)	0.72 ±0.10	$8._4$	$8._4$

the figures of the Moonlight concentration[1,3] of calcareous tissue should be interpreted as the figure of the concentration of environmental water, as $\mu\mu c/l$, where the fish had lived since they born as an overall figure. Really the contamination of fish is caused partly by up-take through epithelium directly from environmental water, and partly by intake of contaminated food organisms indirectly. In both procedure, the isotopic dilution ratio must be the same during the procedure.

4. Fall-out Dilution by Depth

By Table 1, the Sr^{90} concentration of water is somewhat related with the depth of the ocean where these fishes inhabited and caught. Thus, these concentrations were checked by the figure of cumulative, amount of fallout on the area around Japan at that time when they lived. The cumulative globe's surface deposit at the end of 1956 around Japan calculated by HIYAMA[3)] is about the same as by MIYAKE[8)] and is about 6 mc/km^2 or 6 mμc/m^2. And, as fishes are two or three years old, approximately a half of that figure would be adequate for that period they grew up. If this amount of Sr^{90} fallen on the surface of the ocean could be diluted by the amount of water down to A meter deep, the Sr^{90} concentration in sea-water must be $3/A$ $\mu\mu c$ per liter. As it is expressed in Fig. 1, the both the

calculated (in black bar) and measured (point at front of fish) figure is almost coincidental, though the two deeper inhabitants have no accurate figure.

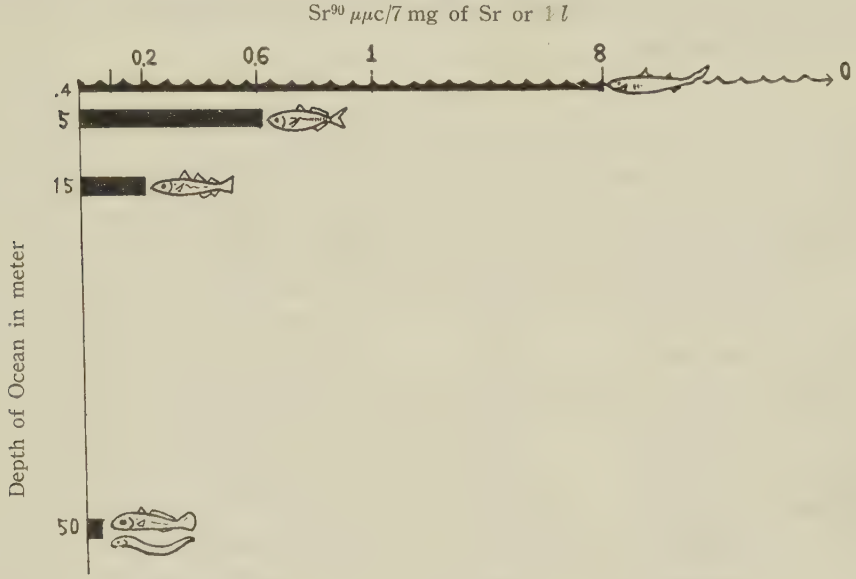

Fig. 1

5. Required Amount of Sample

If the efficiency of Geiger-Muller counter requires 200 dpm in order to get accurate figure of one order, about 100 liter of surface water and about 1,000 liter of deeper (around 50 meter depth) water is necessary at least to be sampled in the recent situation in the North Pacific. However, by a kind of bio-assay as above mentioned, using the precipitation method of separation of strontium from calcium as Dr. Asari's method and the radio-assay of the same method, about 100 g of calcium from fish bone is enough to get stable strontium amount of the same degree of accuracy, and the same amount would be enough to get 200 dpm for radio-assay, except the deep sea inhabitants, at the present level of contamination. (Ca is about 1/3 of ash in fish bone.)

6. Fall-out Accumulation in Sea-Water

About one to five hundred grams of clam shell (*Paphia philippinarum*) collected from the two locality, the one at shore close to a small river mouth and the other off shore, near Fisheries Laboratory of University of Tokyo, at Ikawazu, Aichi Prefecture, in succeeding three winters (1954 to 1956) was chemically analysed by Dr. Asari's laboratory on amount of stable strontium and radio-assayed by Dr. Yamasaki's laboratory as mentioned before. And, three other sample of the same shell from Tokyo Bay was measured by the same way.

As shown in Table 2, Sr^{90} concentration in ratio to the stable strontium in

these shell, between the two spots, in-shore and off-shore, at Ikawazu, is not significant, but less in Tokyo bay than these. Fig. 2 was made to express the increase of the concentration to compare with that of calculated accumulated Sr^{90} amount on globe surface[8].

Table 2.

Locality	Date of Collection	Ca % in shell	Sr/1000 Ca	Sr 90 $\mu\mu$c per 1 g of Ca	Sr 90 $\mu\mu$c per 7 mg of Sr
Tokyo Bay	1956 Feb.~Apr.	38.5	2.9	0.04 ±0.02	0.1_1
〃	1956 Dec.	38.5	2.9	0.098±0.02	0.2_4
〃	1957 Apr.	38.2	3.0	0.23 ±0.03	0.5_3
Ikawazu In-shore	1954 Nov.	38.5	2.9	0.03 ±0.03	0.0_7
〃	1955 Nov.	38.5	2.9	0.14 ±0.05	0.2_7
〃	1956 Dec.	38.4	3.3	0.31 ±0.02	0.6_4
Ikawazu Off-shore	1954 Nov.	38.2	2.9	0.03 ±0.02	0.1_8
〃	1955 Nov.	38.2	3.3	0.24 ±0.03	0.5_0
〃	1956 Dec.	38.1	3.5	0.31 ±0.03	0.5_9

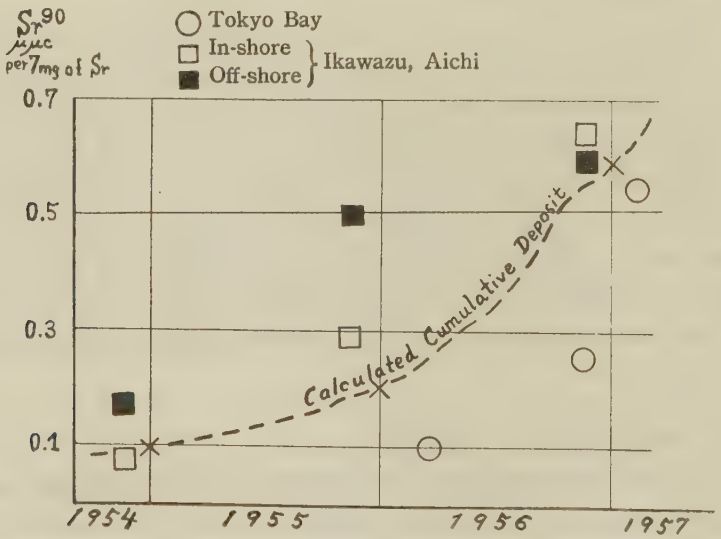

Fig. 2.

Comparing the Moonlight concentration of Sr^{90} in shell to that cumulative surface deposit of respective date of harvest, the depth of the water to dilute the fall-out is about 10 meter (so the graph of cumulative ground deposit is plotted by that dilution), if we could neglect the influence by flow-out of the river water.

As actually this shell fish lives over one year in a zone of around 5 meter or less deep the figures here calculated would not be irrational.

7. Flow-out Influence in the Pacific

The above described data is not enough to clear out the role of river-water in the concentration of coastal water.

In previous chapters, the author merely considered a homogeneous distribution of Sr^{90} by fall-out. However, though the waste from industrial pile might not have influence upon the Pacific water yet, the author found some influence by flow-out from the Marshal Islands in the South Pacific mainly by the test firing of nuclear weapons during 1954.

By the survey of the Shunkotsu-maru a few months after the detonation in 1954, a clear pattern of flow-out of fission products from the turget area was recognized as reported by Miyake and others[9], but the pattern was almost faded away or scattered widely in the Pacific by flow and dilution, when a Japanese and U.S. boats surveyed several months later from her. During these survey, no Sr^{90} concentration data was obtained on both sea-water and the organisms.

However, the Shunkotsu-maru brought back 25 individuals 8 vertebra bones and caudal fins of tuna-like fishes in her second survey in 1956 by the request of the author, and the stable strontium is chemicaly analysed by Mr. Chiba and radio-assayed by Mr. Ichikawa as already reported.[10] Among the 25 individuals, the Moonlight strontium-90 concentration of bone and fin of most of them were below the detectable level (5 $\mu\mu$c/7 mg of Sr in this survey), but 6 individuals show 7.5 to 24 $\mu\mu$c/7 mg of Sr, and the highest was 169 of the same unit, in a large specimen of Black Merlin.

By the approximate measure on the ratio of Sr^{89} to Sr^{90} in that bone, it is clear that Sr^{90} of this originated from the test of the two years ago mostly.

This tells that the environmental water where this fish had inhabited is 169 $\mu\mu$c per liter in Sr^{90} concentration in average, during the period the fish grown up to the size, without considering physical and physiological decay. Actually, as Black Merlin of this size is several years old, the turn-over of Sr in bone by environmental Sr during two years would not be complete. So, the actually sea-water concentration the fish encountered some days must be higher than this level, and ten to hundred times of the level of fall-out contamination. Actually, such heavy contamination of fish is caused by taking contaminated food, small fish, but the food organisms itself must be equilibrium to the environmental water in the same ratio in the isotopic dilution. The fact would tell that such high Sr^{90} concentration in the South Pacific in probably a small area existed near the turget area, from where a certain amount of Sr^{90} was flowing out to the ocean to make such a high concentration there.

Acknowledgement

The authors express their hearty thanks to Dr. Tamiya ASARI, Mr. Morito CHIBA and Mr. Tadashi ARIKI for their sincere effort to get stable strontium amount by chemical analysis, and to Dr. Fumio YAMASAKI and Mr. Akira HASHIZUME for elaborated radio-assay.

Summary

1) By chemical analysis and radio-assay of calcareous tissue of marine organisms, Sr^{90} concentration obtained in term of a isotopic dilution ratio (Moonlight Unit) can tell the concentration in environmental water as an overall figure since the fish born.

2) Sr^{90} concentration in bone of five fish kinds inhabited in various depth and caught at the end of 1956 shows a reasonable value seeing from the dilution of fall-out calculated for that time by the layer of water down to depth of inhabitation.

3) To get accurate figure of one order, the concentration of sea-water around Japan in the end of 1956 requires 100 *l* for surface water and 1,000 *l* for deep (about 50 m) water. For the same degree of accuracy, about 100 to 1,000 g of calcium in shell or dried fish bone can work as the material for bio-assay.

4) Clam shell collected in coast during past three years had Sr^{90} concentration in the similar tendency as the calculated cumulative deposit on earth's surface.

5) By Sr^{90} concentration of bone and fin of tuna-like fishes caught in South Pacific, the existence of intensive flow-out from the test spot was recognized.

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The Amount of Up-take of Strontium by Marine Fish from the Environment of Various Concentration of Calcium and Strontium

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1. Introduction

The authors reported[1] already that puffer and goby took up the radio-strontium with the same ratio to the stable strontium from the environmental water of various isotopic dilution ratio.

Here, the authors hoped to know whether the strontium concentration in fish muscle and bone could be affected by the concentration of strontium and calcium in environmental water or not.

For that purpose, the gobioid fishes were reared in sea water containing various amount of strontium and calcium prepared by adding chemical reagents to the natural oceanic water.

The strontium in sea water was labeled with radioactive strontium, Sr^{90} and the amount of strontium in fish bone and muscle was calculated based on the results of radioassay of Sr^{90}.

The rearing experiments were done in aquarium of Misaki Marine Biological Station of University of Tokyo mainly and partly in the laboratory of University of Tokyo.

Besides these experiments newly done, the available results of the former experiments[1] were also included here for the consideration altogether.

The authors are indebted to Mr. T. Ariki for analysis of strontium in calcium chloride added to the sea water of the experiments.

2. Rearing Experiments in Water of Different Concentration of Strontium

From 21st to 25th of August, 1956, a species of marine goby, *Chasmichthys gulosus* "Dorome" (body weight 2-3 gr.) was reared about 10 individuals in a group in tanks filled by 60 *l* of sea water of different strontium concentration. The one is by normal oceanic water (7 mg Sr/*l*) (Experiment No. 8), and the another is by diluted sea water (1.75 mg. Sr/*l*) (Experiment No. 9) which is consisted of 15 *l* of oceanic water and 45 *l* of distilled water. The water temperature was about 23°C during the experiment. Sr^{90} was added to the water in all the tanks so as

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Table 1. The amount of Sr^{90} and Sr taken in muscle and bone of goby in various experiments.

	I	II	III	IV	V	VI	VII
Period	July, 15th～20th, 1957	〃	〃	〃	July, 21st～26th, 1957	〃	〃
Concentration of Sea Water	Normal Sea Water	〃	〃	〃	〃	〃	〃
Water temp.	25°C	〃	〃	〃	〃	〃	〃
Ca mg/*l*	400	400	400	400	600	1,000	2,000
Sr mg/*l*	50	25	15	7	7.12	7.36	7.95
Sr/Ca ×100	12.5	6.25	3.75	1.75	1.18	0.74	0.40
Sr^{90} μc/*l*	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Sr^{90} μc/mg of Sr	0.15	0.50	0.50	1.07	1.06	1.02	0.94

Muscle	10^{-5} Sr^{90} μc/g	10^{-5} Sr mg/g	10^{-5} Sr^{90} μc/g	10^{-5} Sr mg/g	10^{-5} Sr^{90} μc/g	10^{-5} Sr mg/g	10^{-5} Sr^{90} μc/g	10^{-5} Sr mg/g	10^{-5} Sr^{90} μc/g	10^{-5} Sr mg/g	10^{-5} Sr^{90} μc/g	10^{-5} Sr mg/g	10^{-5} Sr^{90} μc/g	10^{-5} Sr mg/g
1	29	190	36	120	18	36	17	16	20	19	16	16	12	13
2	21	140	23	80	20	40	20	19	23	22	9	9	11	12
3	24	160	30	100	20	40	16	15	21	20	13	13	12	13
4	27	180	21	70	31	62	13	12	11	10	13	13	12	13
5	21	140	26	90	23	46	15	14	15	14	15	15	11	12
6	26	170	33	110	27	54	24	22	17	16	8	8	11	12
7	14	90	26	90	14	28	20	19	12	11	11	11	10	11
8	34	220	37	120	25	50	15	14	17	16	12	12	12	13
9	33	220	27	90	37	74	24	22	15	14	12	12	16	17
10			37	120			23	21	13	12				
Mean	25±6	170±42	30±6	99±20	24±9	48±18	18±4	18±4	15±4	14±4	12±4	12±4	12±2	13±2

Bone		10^{-3} Sr^{90} $\mu c/g$	10^{-3} Sr mg/g	10^{-3} Sr^{90} $\mu c/g$	10^{-3} Sr mg/g	10^{-3} Sr^{90} $\mu c/g$	10^{-3} Sr mg/g	10^{-3} Sr^{90} $\mu c/g$	10^{-3} Sr mg/g	10^{-3} Sr^{90} $\mu c/g$	10^{-3} Sr mg/g	10^{-3} Sr^{90} $\mu c/g$	10^{-3} Sr mg/g	10^{-3} Sr^{90} $\mu c/g$	10^{-3} Sr mg/g
	1	2.5	17	3.2	10.6	2.8	5.6	1.2	1.1	3.4	3.2	2.4	2.4	0.76	0.80
	2	2.7	18	2.1	7.0	4.9	9.8	2.2	2.1	2.5	2.4	2.1	2.1	1.17	1.24
	3	3.1	20	3.4	11.3	1.0	2.0	2.8	2.6	2.4	2.3	1.6	1.6	1.33	1.41
	4	3.7	24	2.2	7.3	4.3	8.6	2.0	1.9	0.9	0.9	1.7	1.7	0.76	0.80
	5	2.8	18	3.6	12.0	3.6	7.2	1.5	1.4	2.2	2.1	1.6	1.6	0.93	0.98
	6	3.1	20	2.3	7.7	3.2	6.4	2.4	2.2	1.9	1.8	1.2	1.2	0.62	0.66
	7	3.1	20	3.1	10.3	3.2	6.4	1.5	1.4	1.6	1.5	1.2	1.2	0.59	0.62
	8	2.7	18	2.5	8.3	4.2	8.4	2.2	2.1			1.0	1.0	0.71	0.75
	9	2.8	19	2.9	9.7	2.2	4.4	2.5	2.3	1.2	1.1	1.5	1.5	0.63	0.67
				2.8	9.3			1.8	1.7	2.0	1.9	1.0	1.0		
	Mean	2.9±0.5	19±3	2.8±0.5	9.3±1.7	3.3±1.2	6.6±2.4	2.0±0.5	1.9±0.5	2.0±0.8	1.9±0.7	1.5±0.5	1.5±0.5	0.83 ±0.26	0.88 ±0.28

		VIII	IX	X	XI	XII
Period		Aug. 21st ~ 25th, 1956	〃	Sept. 25th ~ Oct. 1st, 1956	〃	〃
Concentration of Sea Water		Normal Sea Water	15l Sea Water +45l dist. Water	20l dist.Water 20l dist Sea Water	10l Sea Water +30l dist.Water	〃
Water	temp.	23°C	23°C	22°C	22°C	22°C
Ca	mg/l	400	100	200	100	100
Sr	mg/l	7	1.75	3.5	35	1.75
Sr/Ca	×100	1.75	1.75	1.75	35	1.75
Sr^{90}	$\mu c/l$	2	2	10	10	10
Sr^{90}	μc/mg of Sr	0.286	1.14	2.86	0.286	5.72

Table 1. Continued.

Muscle		10^{-5} Sr^{90} $\mu c/g$	10^{-5} Sr mg/g	10^{-5} Sr^{90} $\mu c/g$	10^{-5} Sr mg/g	10^{-5} Sr^{90} $\mu c/g$	10^{-5} Sr mg/g	10^{-5} Sr^{90} $\mu c/g$	10^{-5} Sr mg/g	10^{-5} Sr^{90} $\mu c/g$	10^{-5} Sr mg/g
	1	2.2	7.7	4.4	3.8	15.9	5.6	21	73	15	2.5
	2	1.9	6.7	3.4	3.0	10.1	3.5	17	58	21	3.7
	3	2.7	9.5	10.0	8.8	6.9	2.4	17	59	13	2.3
	4	0.5	1.8	6.8	6.0	5.3	1.9	26	91	44	7.7
	5	2.1	7.4	6.1	5.3	7.6	2.8	49	170	32	5.6
	6	3.1	10.9	4.1	3.6	11.4	4.0	21	75	32	5.5
	7	1.8	6.3	14.3	12.5	15.3	5.4	37	130	38	6.7
	8	1.3	4.6	4.3	3.8	7.5	2.6			17	2.9
	9	1.3	4.6	3.2	2.8	7.6	2.7			8	1.3
	10	6.9	24.2	3.3	2.9	10.5	3.7				
	11	3.8	13.3	6.5	5.7	21.9	7.7				
	12	3.1	10.9	5.8	5.1						
	Mean	2.6±1.5	9.0±5.2	6.0±3.3	5.3±2.9	10.9±5.0	3.8±1.7	27±14	94±49	24±12	4.2±2.1
Bone		10^{-3} Sr^{90} $\mu c/g$	10^{-3} Sr mg/g	10^{-3} Sr^{90} $\mu c/g$	10^{-3} Sr mg/g	10^{-3} Sr^{90} $\mu c/g$	10^{-3} Sr mg/g	10^{-3} Sr^{90} $\mu c/g$	10^{-3} Sr mg/g	10^{-3} Sr^{90} $\mu c/g$	10^{-3} Sr mg/g
	1	0.91	3.2	0.76	0.67	4.8	1.7	7.4	26	7.7	1.3
	2	0.86	3.0	0.56	0.49	5.9	2.1	6.3	22	5.5	1.0
	3	0.95	3.3	0.58	0.51	4.6	1.6	6.3	22	6.8	1.2
	4	0.81	2.8	1.23	1.08	5.8	2.0	2.4	8	10.3	1.8
	5	0.62	2.2	1.34	1.17	4.4	1.5	7.3	26	8.4	1.5
	6	0.95	3.3	0.22	0.19	4.7	1.6	6.5	23	16.0	2.8
	7	0.53	1.9	0.80	0.70	6.2	2.2	7.8	27	4.1	0.7
	8	0.72	2.5	0.66	0.58	7.3	2.6			5.8	1.0
	9	0.93	3.3	0.97	0.85	2.2	0.8			3.0	0.5
	10	0.68	2.4	0.87	0.76	3.5	1.2				
	11	0.55	1.9	0.98	0.86	4.4	1.5				
	12	0.62	2.2	1.37	1.20						
	Mean	0.76±0.16	2.7±0.6	0.86±0.33	0.80±0.31	4.9±1.4	1.7±0.5	6.3±1.8	22±6	7.5±3.9	1.3±0.7

Table 2. The mean value of the amount of strontium taken in goby from sea water of various concentration of calcium or strontium.

Experiment	Fish	Period	Water temp.	Volume of water	Number of individuals	Concentration of Sea Water	Ca mg/l of water	Sr mg/l of water	Sr/Ca $\times 100$ in water	Muscle 10^{-5} mg Sr/g	Bone 10^{-3} mg Sr/g
I	Dorome	July 15th ~ 20th, 1957	25°C	50l	9	1	400	50	12.5	170	19
II	〃		〃	〃	10	1	400	25	6.25	99	9.3
III	〃		〃	〃	9	1	400	15	3.75	48	6.5
IV	〃		〃	〃	10	1	400	7	1.75	18	1.9
V	〃	July 21st ~ 26th, 1957	〃	〃	10	1	600	7.12	1.18	14	1.9
VI	〃		〃	〃	9	1	1,000	7.36	0.74	12	1.5
VII	〃		〃	〃	9	1	2,000	7.95	0.40	13	0.88
VIII	〃	Aug., 21st ~ 25th, 1956	23°C	60l	12	1	400	7	1.75	9.0	2.7
IX	〃		〃	〃	12	1/4	100	1.75	1.75	5.3	0.80
X	Mahaze	Sept. 25th ~ Oct. 1st, 1956	22°C	40l	11	1/2	200	3.5	1.75	3.8	1.7
XI	〃		〃	〃	7	1/4	100	35	35	94	22
XII	〃		〃	〃	9	1/4	100	1.75	1.75	4.2	1.3
XIII	〃	July 27th ~ Aug. 4th, 1956	24°C	20l	7	1	400	7	1.75	15	3.4
XIV	〃		〃	〃	15	1/2	200	3.5	1.75	13	3.3
XV	〃		〃	〃	14	1/4	100	1.75	1.75	12	3.3

to make the concentration of it as 2 $\mu c/l$.

Next, from Sept. 25th to Oct. 1st, 1956, the second series of experiments was done rearing Japanese common goby, "Mahaze", *Acanthogobius flavimanus* (body weight 3–5 gr.) about 10 individuals in a group, in three tanks filled by 40 l of diluted sea water of three different concentration. The first (Experiment No. 10) (3.5 mg Sr/l) is of 20 l sea water and 20 l distilled water, the second (Experiment No. 11) (35 mg Sr/l) is of 10 l sea water and 30 l distilled water and strontium nitrate added artificially so as to make the concentration as 35 mg Sr/l and the third (Experiment No. 12) (1.75 mg Sr/l) is of 10 l sea water and 30 l distilled water. Sr^{90}

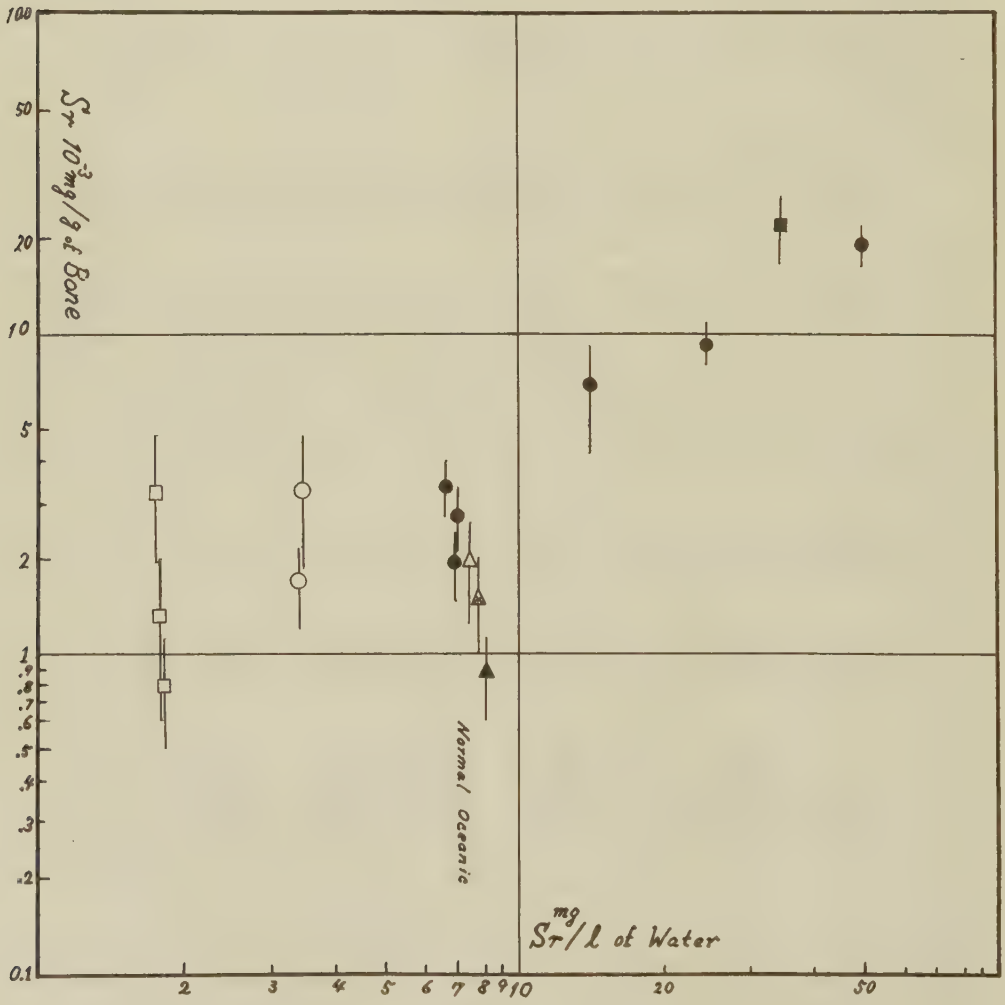

Fig. 1. The relationship between the amount of strontium taken in bone of goby and the strontium concentration of sea water.

▲ 2 g Ca/l ▲ 1 g Ca/l △ 600 mg Ca/l
● 400 mg Ca/l ○ 200 mg Ca/l □■ 100 mg Ca/l

was added to each water so as to make the concentration as 10 $\mu c/l$. The water temperature during the experiment was about 22°C.

The third series of the experiment was done in 1957, from July 15th to 20th, rearing "Dorome" (body weight 1–1.5 gr.) about 10 individuals in a group, in tanks filled by 50 l of sea water to which strontium nitrate was added to make four different strontium concentration. The first (Experiment No. 4) has it as 7 mg/l, the second (Experiment No. 3) as 15 mg/l, the third (Experiment No. 2) as 25 mg/l, and the fourth (Experiment No. 1) as 50 mg/l. The water temperature during the experiment was about 25°C. Sr^{90} was added to water in all the tanks so as to make the concentration as 7.5 $\mu c/l$.

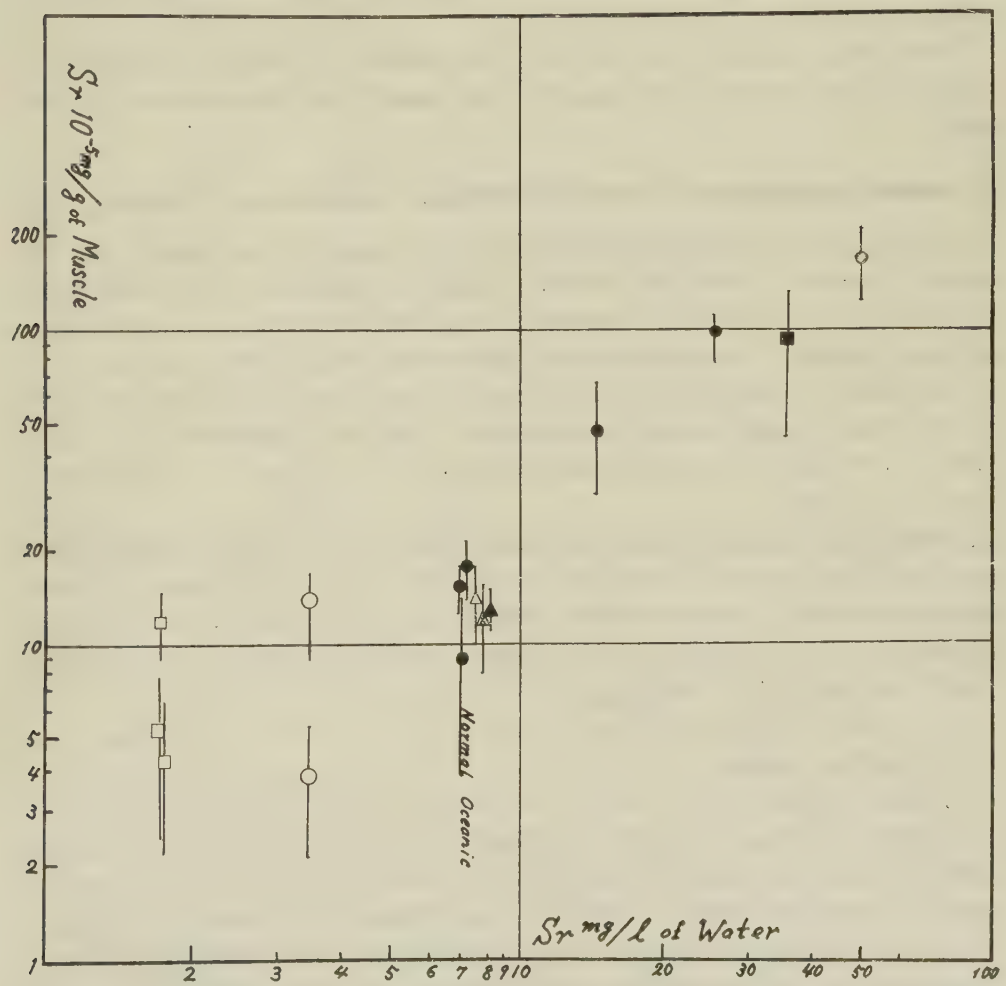

Fig. 2. The relationship between the amount of strontium taken in muscle of goby and strontium concentration of sea water.

▲ 2 g Ca/l ◬ 1 g Ca/l △ 600 mg Ca/l
● 400 mg Ca/l ○ 200 mg Ca/l □■ 100 mg Ca/l

In these series of experiments, a group of fishes was kept alive there, without feeding during 5 to 7 days and was sacrificed for anatomy and radioassay. The amount of Sr^{90} per gram of muscle and bone of these fishes are obtained by radioassay and shown in Table 1.

From these figures and the ratio of Sr^{90}/Sr in water, the amount of total strontium taken by fish from the enviromental sea water was calculated as shown in Table 1 and 2. And Figs. 1 and 2 show the relationships of the amount of strontium taken in fish muscle and bone with strontium concentration in sea water. In Table 2 and Figs. 1 and 2, the results of the series of the experiment already reported in our previous paper[1] were included for over-all consideration. (expressed as Experiment Nos. 13, 14 and 15.)

From these figures, it is clear that the amount of strontium taken both in muscle and bone is large when reared in the water of high concentration of strontium.

3. Rearing Experiments in Water of Different Concentration of Calcium

To see the relation of the concentration of calcium in sea water with the amount of up-take of strontium by fish, a series of experiments was under-taken from July 21st to 26th, 1957, in parallel to the third series of the experiment in preceding chapter in the same condition, except the rearing water in tanks.

The water in tanks was prepared adding calcium chloride to normal sea water to make three different calcium concentrations. The first (Experiment No. 5) has calcium as 600 mg/*l*, the second (Experiment No. 6) as 1 g/*l* and the third (Experiment No. 7) as 2 g/*l*.

However, as calcium chloride ($CaCl_2 \cdot 2H_2O$) added to the water includes 0.016% (metal) of strontium (by chemical analysis by Mr. ARIKI), the strontium concentration of sea water increased slightly when the calcium concentration in water was increased artificially. Therefore, the strontium concentration of sea water in Tables 1 and 2 was corrected by these figures.

The results obtained were shown in Tables 1, 2, Figs. 3 and 4 with all other data of the preceding chapter.

As shown in Figs. 3 and 4, contrary to the Figs. 1 and 2, the amount of strontium taken by fish both in muscle and bone was not large by the high concentration of calcium in water, but was large in tissue remarkably by high concentration of strontium in water. Moreover, a faint trenary of the reduction of amount of strontium taken by fish by high calcium concentration in water, was recognized about the data excluding these which had more strontium concentration than normal sea water

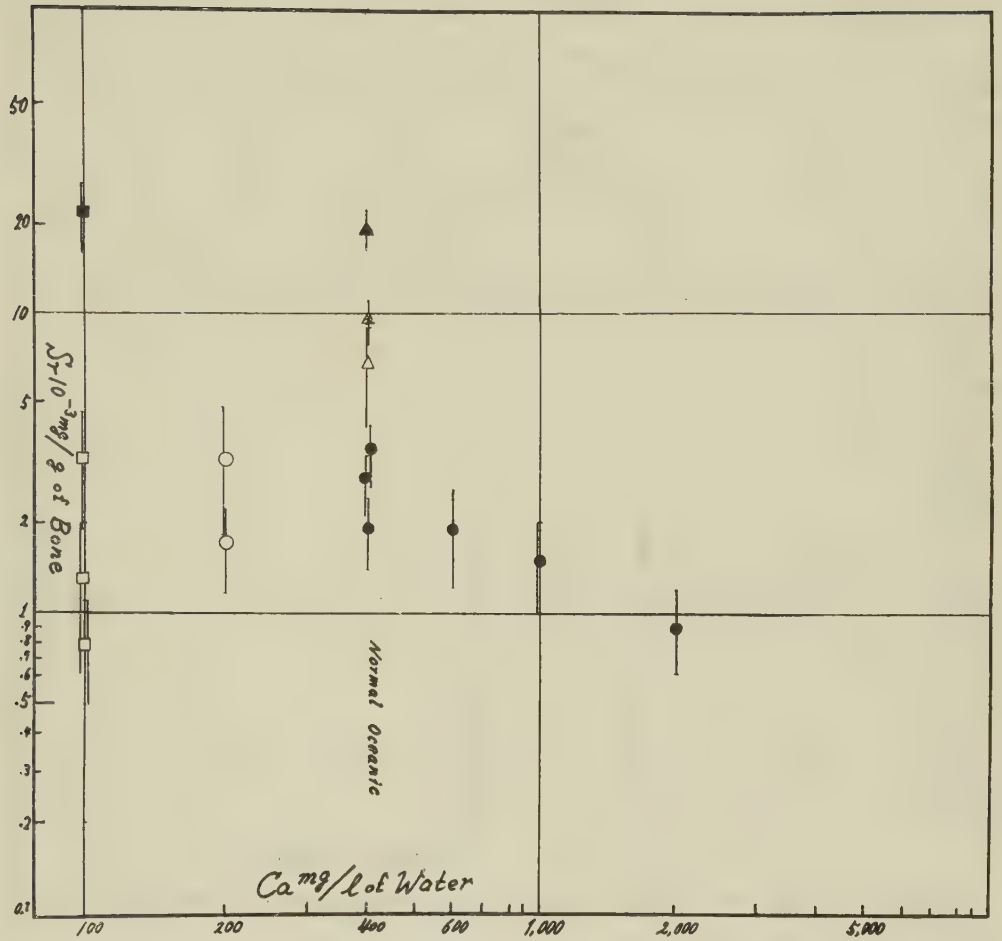

Fig. 3. The relationship between the amount of strontium taken in bone of goby and the calcium concentration of sea water.

▲ 50 mg Sr/l ■ 35 mg Sr/l ◬ 25 mg Sr/l
△ 15 mg Sr/l ● 7 mg Sr/l ○ 3.5 mg Sr/l □ 1.7 mg Sr/l

4. Conclusion and Discussion

The results of these series of experiments as shown in Table 2 and the arrangement of data as in Figs. 1–4 persuade the authors to conclude as follows. (1) That the higher the concentration of strontium in environmental water, the more the amount taken in fish tissue. (2) The higher concentration of calcium in water does not make the amount of up-take larger. Moreover, a faint trenary of the reduction of up-take was shown in higher concentration of calcium, though it is not significant.

This finding of us is quite similar to the fact that Rice[2] (1956) found about

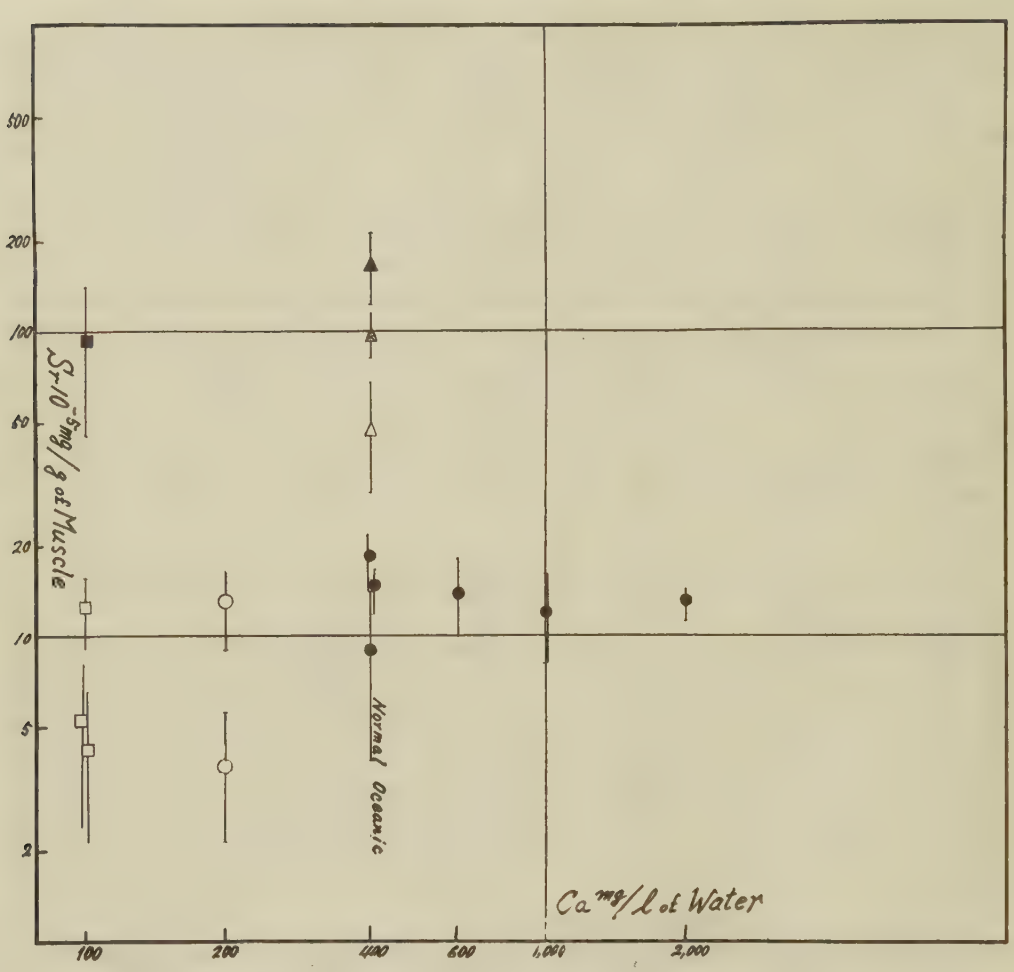

Fig. 4. The relationship between the amount of strontium taken in muscle of goby and the calcium concentration of sea water.

▲ 50 mg Sr/*l* ■ 35 mg Sr/*l* ◬ 25 mg Sr/*l*
△ 15 mg Sr/*l* ● 7 mg Sr/*l* ○ 3.5 mg Sr/*l* □ 1.7 mg Sr/*l*

the up-take of radiostrontium by marine phyto-plankton. In these experiments, the amount of strontium taken-up by fish in to these tissues, which were determined by the amount of labelled Sr^{90} by radio-assay, must be the same as the total amount of strontium in these tissues, if the turn-over of this element during the rearing experiment is complete - in other words, when all the elements in tissue were replaced by the new comers from the environment. By the experiments reported in the authors' previous paper, we understood that the turn-over was complete in muscle, while it was about 10% in bone in the case of these fishes reared 5–7 days without feeding.

Therefore, if the concentration of total calcium (calcium plus strontitum, but

strontium is negligible in amount) could be constant in these tissues, the figures of strontium concentration in tissues must be proportional to the ratio of strontium to calcium (Sr/Ca). As the Sr/Ca ratio varies greatly in the water in the experiments, Figs. 5 and 6 were made from Table 2 to see the relation of the Sr/Ca ratio in water. The Figs. 5 and 6 tell that proportional relation between the both is rather clear, except in cases reared in diluted sea water. However, as no data on calcium concentration in fish tissue is available, it is hard to say at present moment that the Sr/Ca ratio is proportional, both in sea water and fish tissue. For the reference, there are two of works telling that calcium concentration in

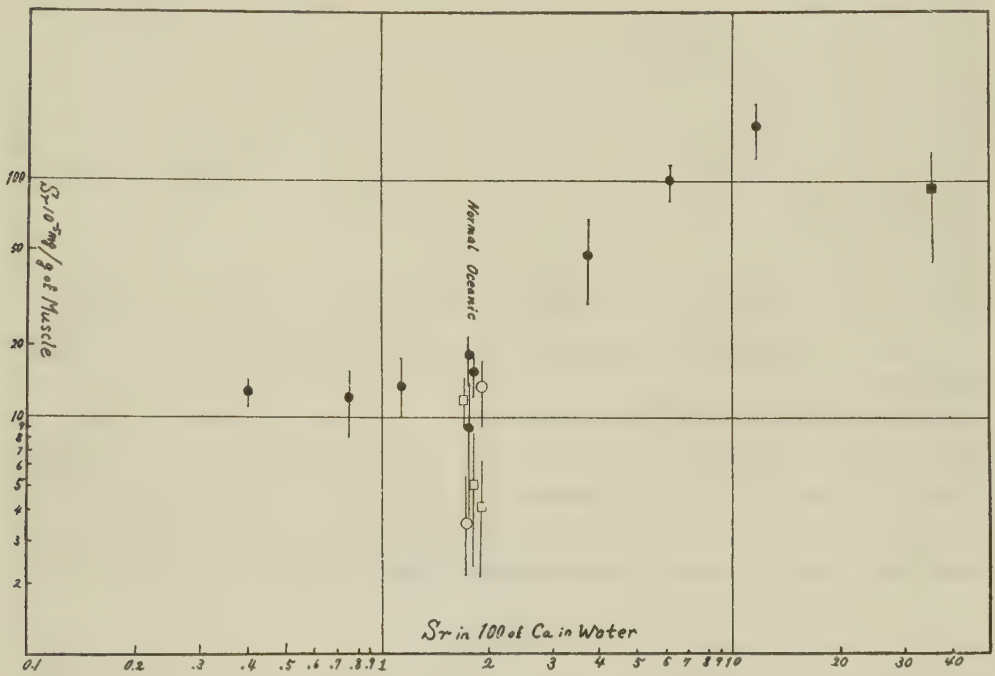

Fig. 5. The amount of strontium taken in muscle of goby from the water of various Sr/Ca ratio.

● Undiluted sea water ○ Diluted sea water in 1/2
□ Diluted sea water in 1/4 ■ Diluted sea water in 1/4 plus Sr.

tissue is affected by calcium concentration of water in fresh water fish. The one is reported by Usui and others[3] about *Hypomesus olidus* that the fish from Lake Kasumi where more calcium is in water has higher concentration of calcium in muscle than the fish caught from Lake Hinuma where lower calcium is in water. The another is about Carp and Crusian Carp by Kaplanski and Boldirewa[4] that the calcium in fish muscle increased by adding $CaCl_2$ into the rearing water. Therefore, only the matter we can say is that the strontium concentration in tissue is affected by strontium concentration in water rather proportionally, just like

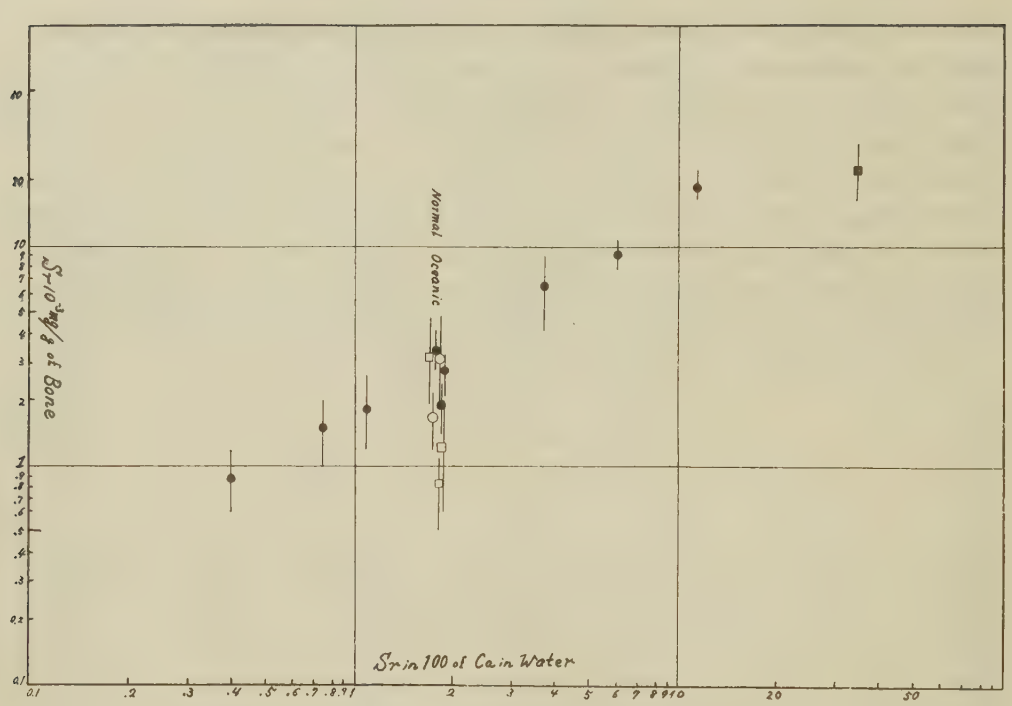

Fig. 6. The amount of strontium taken in bone of goby from the water of various Sr/Ca ratio.

The same denotation as in Fig. 5 was used.

higher calcium concentration in rearing water brings more calcium in fish muscle. It must be noted here that in nature, the variation of concentration of these material in the environmental water does not occur in marine fish, because the oceanic sea water has rather constant concentration of both strontium and calcium.

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Morphometric Characteristics of the Albacore, *Germo germo*, from the Northwest Pacific

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1. Introduction

In the Northwest Pacific along the east coast of Japan, two kinds of fishery for albacore have been in operation since several decades. One of them, the pole-and-line fishery is carried in early summer near the coast, and the other is by long line during winter in the off-shore waters. By the former relatively small fish that comes up to the surface so often is caught, and by the latter relatively large fish that lives in the deeper layers of the water is taken. The catches of these two kinds of fishery for albacore were examined to see the morphological differences between each other by morphometry, before comparison of morphometric characters of other groups caught from various localities in the Indo-Pacific area are started.

In the three years from 1955 to 1957, we were able to collect five samples from this area. The results obtained from these samples have been divided under four headings, as referred to below.

a) Relative growth of the Northwest Pacific albacore
b) Comparison of the same sized albacore
c) Comparison of the differently sized albacore
d) Comparison of the albacore taken by the two different gears

From this study, we could determine, what regression lines fit the relative growth of each character over a limited body size range; what character has a great variability within the same population; and whether or not the gear and body size affect the morphometrical characteristics of the albacore.

2. Method and materials

Samples used in this study are tabulated in Table 1, showing the origin, fishing date, number of fish, range and composition of body size and fishing gear.

All specimens were measured by K. Kurogane at the Tokyo Central and Yaizu Fish Market. Measurements were made in millimeters with slide calipers, or with a pair of dividers for short lengths such as the first dorsal spine length, maxillary length and diameter of iris, in accordance with the techniques described by Marr and Schaefer (1949)[1].

Table 1

Origin, date taken, number of fish, range and composition

Origin		Date taken	No. of fish	Range of body length (mm.)
33°N–37°N	143°E–151°E	June, 1955	44	768– 952
32°N–37°N	147°E–158°E	June, 1956	76	483– 892
32°N–36°N	145°E–151°E	June, 1957	66	481– 921
37°N–40°N	173°E–175°W	Aug.–Oct., 1955	62	812–1170
35°N–39°N	155°E–165°E	Sept.–Oct., 1956	40	740–1123

Eighteen measurements were selected, namely: body length; head length; the insertion of the first dorsal, second dorsal, anal, ventral and pectoral fins; first dorsal base; second dorsal to caudal; anal to caudal; first dorsal spine length; the length of the second dorsal; anal and pectoral fins; body depth; spread caudal; maxillary length and diameter of iris. These characters have been illustrated in our report on the Equatorial Pacific yellowfin tuna[2].

Our specimens ranged in length from 481 to 1,170 mm.. Over the entire size range examined, the relative dimensions of some body parts seem to be better fitted by a slight curvilinear regression, but for fish of body length about 75 cm. and over the graph well approximates a straight line, or is transformed to a linear relation. Accordingly, in order to establish the morphometrical characteristics of the albacore population, we have computed for each dimension measured the linear mean-square regression on the body length, or on the head length in the cases of maxillary length and diameter of iris. Comparison of the linear regressions may be made by means of covariance analysis (KENDALL 1948)[3].

3. Results

Relative growth of the Northwest Pacific albacore

Over the range of size in our samples, we have plotted the body part's length against the body length or against the head length on a graph to see their relation.

The rate of growth of the pectoral fin is less than that of the body length over the range of sizes examined. The relationship between pectoral fin length (y) and body length (x) may be well shown by an equation of the type $y=a+b\log x$, so that a linear regression is obtained by plotting the fin length against logarithms of body length.

There seem to be slightly an inflection at about 70 cm. body length size in the relative growth of several characters. In these characters, such as head length, the insertion of the first dorsal, ventral and pectoral fins, length of second dorsal and anal fins, and diameter of iris, their growth, relative to body or head length

of body size and fishing gear for each sample.

Size composition								Fishing gear
40	50	60	70	80	90	100	110 (cm.)	
			15	21	8			Pole-and-line
1	14	17	30	14				Pole-and-line
5	10	14	17	15	5			Pole-and-line
				18	17	12	15	Long line
			3	26	8	2	1	Long line

in the smaller specimens is faster than that of the larger ones, while the first dorsal base shows faster growth in the larger ones. Such results well agree with GODSIL's results (1948)[4]. He fitted the regression lines of slight curvilinearlity to body part lengths that were plotted against body length or head length for albacore from the west coast of U.S.A.. He found that the relationship between body part length and body length may be well expressed in the form:—

$$y=a+bx+\frac{c}{x}.$$

The value of the constant c shows the degree of curvilinearlity and its ascending or descending tendency. As shown in his table (Appendix E), characters such as their growth rate to body length at young ages, are, when fast have a negative value of c and when slow have a positive value of c.

However, when we discuss about the specimens divided into sub-samples at about 75 cm. body length, these characters fit well in a straight line graph. Generally it is recognized that curvilinear regressions result in smaller variance about them than linear regressions. But from the graphs of relative growth and from the practical standpoint to compare only rather large sized fish samples, the difference between these well fitted curves for all sized specimens, and straight lines for the sub-groups stratified by size, seems to be only slight. The analysis of the curvilinear regression is greatly laborious to calculate as compared with the linear regression. This has been pointed by ROYCE (1953)[5].

Comparison of the same sized albacore

Size frequency distributions of the albacore by the pole-and-line fishery, late in June, had the three modes at 50, 65 and 76 cm. in 1956 and at 53, 67 and 80 cm. in 1957. But in 1955, it showed a unimodal distribution, at 80 cm..

So, we divide each sample taken in 1956, 1957 by their size into three sub-samples. These sub-samples seem to differ in age as shown by NOSE et al (1957)[6]. The sub-samples under 60 cm. body length in 1956, 1957 are compared in 17 char-

acters (above mentioned) by covariance analysis, and only in anal to caudal the regressions are different at 5% significant level. The sub-samples ranging from 60 cm. to 70 cm. body length in 1956 and 1957, are compared, too. In the relation of first dorsal base against body length the difference is significant, but other 16 characters do not show the difference at 5% significant level.

However, comparing the samples over 75 cm. size group, we can find the difference between them in a few characters. Three samples which were taken each year from 1955 to 1957, are compared by covariance analysis. The regression difference is highly significant in body depth, and significant at 5% level in snout to anal, second dorsal fin length, maxillary length and diameter of iris. Other 12 characters do not show the significant difference.

Two samples taken by the long line fishery are compared. These samples are taken from the rather distant fishing grounds in the Northwest Pacific. Anal to caudal and maxillary length show the difference but other 15 characters do not show any significant difference.

We could not find any precise factors to produce such heterogeneity between samples of nearly the same body size, taken from the same area. These heterogeneity have been shown by GODSIL (1948) and SCHAEFER (1952, 1955)[7),8)], too. GODSIL has suggested that such differences are due to incomplete mixing of the population of a region. SCHAEFER has pointed that such heterogeneity may be produced by the differences in size composition of samples. The validity of SCHAEFER's suggestion will be shown in the next section. At any rate, we could find that the variability is great in the relative growth of body depth and distance from anal to caudal, but little in other characters. It is necessary to take such results into consideration, when we judge the differences between regions.

Comparison of the differently sized albacore

Specimens under 75 cm. body length are divided into two size groups as mentioned above. So we compare the sub-sample under 60 cm. body length with those ranging from 60 cm. to 70 cm. and cannot find any significant difference between them in the 17 characters.

But when we compare the sub-sample under 70 cm. with that over 75 cm., taken by the pole-and-line fishery, many characters show the difference in their regression lines. Mainly, these differences are caused by the regression coefficient difference. As shown in Table 2, sample under 70 cm. has a larger regression coefficient in head length, the insertion of the fins, fin length, maxillary length and diameter of iris, but a smaller regression coefficient in first dorsal base, second dorsal to caudal and anal to caudal than the sample over 75 cm.. So, when we compare such different body size samples, we are apt to interpret the size difference as an indication of the population difference. SCHAEFER (1955) pointed this difference as follows:

Table 2

Comparison of body proportions between albacore under 70 cm. and over 75 cm. body size taken by the pole-and-line fishery. Data show the variance ratio and regression coefficient of each sample and the asterisks show the significance. F_r is the variance ratio to test the significance of the regression difference. F_b to test the regression coefficient difference and F_a to test the adjusted mean difference. The regression coefficient of albacore under 70 cm. body size are shown with b_1 and over 75 cm. with b_2.

Body character	F_r	F_b	F_a	b_1	b_2
Head length	36.26***	70.94***	(1.13)	0.2995	0.2398
Snout to 1st dorsal	5.86**	11.72***	(<1)	0.3223	0.2828
Snout to 2nd dorsal	1.67	2.81	<1	0.5662	0.5476
Snout to anal	2.98	5.08*	(<1)	0.6218	0.5925
Snout to ventral	10.08***	19.72***	(<1)	0.3343	0.2906
Snout to pectoral	22.18***	44.35***	(<1)	0.3087	0.2455
1st dorsal base	3.10*	5.82*	(<1)	0.2491	0.2727
2nd dorsal to caudal	1.85	3.49	<1	0.4734	0.4984
Anal to caudal	1.82	1.90	1.74	0.4010	0.4225
1st dorsal spine length	<1	<1	<1	0.1297	0.1235
2nd dorsal length	4.81**	7.48**	(2.06)	0.1569	0.1323
Anal length	5.98**	10.81**	(1.08)	0.1623	0.1367
Pectoral length	4.04*	<1	7.49**	873.8	836.5
Body depth	1.46	2.72	<1	0.2651	0.2908
Spread caudal	<1	1.91	<1	0.3632	0.3244
Maxillary length	3.39*	5.60*	(1.15)	0.3753	0.3354
Diameter of iris	13.00***	22.10***	(3.47)	0.1303	0.0916

N.B. In the case where the regression coefficient difference is significant, the test of the adjusted mean difference has no meaning, i.e. those figures within brackets under F_a.

*: Significant at 5% level

**: Significant at 1% level

***: Significant at 0.1% level

" ....differences may result from the departure of the true relative growth relationship from the simple mathematical relationships used as a basis for covariance analysis, coupled with differences in size-composition of samples."

Comparison of the albacore taken by the two different gears

The long line fishery catches the deep-swimming albacore during the south migrating season. The body size of these albacore range from 74 cm. to 117 cm.. On the other hand, the pole-and-line fishery catches the surface-swimming albacore during the north migrating season. Their body size range from 48 cm. to 95 cm.. In the previous section we have found that the albacore under 70 cm. differ greatly in relative growth with those over 75 cm.. So, when we compare the samples taken by different gears, those samples over 75 cm. in size, taken by the pole-and-line gear are chosen for comparison with the other samples. Three samples by

the pole-and-line fishery and two samples by the long line fishery are compared and the following results are obtained.

As shown in Table 3, five sample regressions differ in snout to anal insertion, body depth and maxillary length at 0.1% or 1% significant level, in anal to caudal and spread caudal at 5% level. Since the regression difference can be divided into the difference of regression coefficients and the difference of adjusted means, we find that the regression difference greatly depends on the difference of adjusted

Table 3

Comparison of body proportions of albacore taken by the different gears. Data shows the variance ratio and the asterisks show the significance.

Body character	F_r	F'_b	F_a
Head length	<1	1.45	<1
Snout to 1st dorsal	1.08	<1	1.89
Snout to 2nd dorsal	1.32	<1	1.81
Snout to anal	4.24***	<1	7.53***
Snout to ventral	1.17	2.18	<1
Snout to pectoral	1.23	1.42	1.03
1st dorsal base	1.25	1.32	1.17
2nd dorsal to caudal	1.44	1.04	1.83
Anal to caudal	2.13*	3.34*	(<1)
1st dorsal spine length	<1	<1	<1
2nd dorsal length	1.70	1.53	1.85
Anal length	1.38	1.72	1.02
Pectoral length	<1	<1	1.33
Body depth	9.94***	2.11	17.40***
Spread caudal	2.45*	<1	4.01**
Maxillary length	2.80**	<1	5.01***
Diameter of iris	1.66	<1	3.39*

means (i.e. the difference of the levels of the regression lines). Accordingly, we estimate the adjusted mean and its 99% confidence interval of each character, basing on the regression coefficient estimated from five samples, excepting the anal to caudal in which five samples have the different regression coefficients at 5% significant level. These values are tabulated in Table 4.

Snout to anal insertion showed the difference in the pole-and-line samples as mentioned above. When we compare these with the long line samples, the difference is greater than that of the pole-and-line samples. The long line albacore have more posteriorly positioned anal fins than the pole-and-line albacore.

The same tendency is recognized in body depth. Generally the body depth of pole-and-line albacore are higher than the long line albacore.

On the other hand, maxillary length shows differences in the same gear sam-

Table 4

Adjusted mean of each body part with its 99% confidence limits, mean standard length in millimeters and estimated regression coefficient.

Body character \ Sample	Pole-and-line 1955	Pole-and-line 1956	Pole-and-line 1957	Long line 1955	Long line 1956	Mean standard length (mm.)	Estimated regression coefficient	No. of fish
Head length	253.4±1.57	254.2±1.86	254.0±1.77	254.5±1.60	254.4±1.60	878.2	0.2482	216
Snout to 1st dorsal	285.8±2.15	285.0±2.55	285.1±2.42	288.4±2.19	286.8±2.19	878.2	0.2852	216
Snout to 2nd dorsal	511.1±2.34	509.5±2.78	511.7±2.64	513.5±2.38	512.3±2.38	878.2	0.5389	216
Snout to anal	556.0±2.77	555.9±3.25	559.4±3.09	563.7±2.79	561.4±2.79	878.4	0.5919	215
Snout to ventral	288.4±2.42	289.1±2.83	289.3±2.70	288.4±2.43	288.9±2.43	878.4	0.3030	215
Snout to pectoral	258.7±1.91	259.3±2.27	259.9±2.16	260.0±1.95	260.7±1.95	878.2	0.2524	216
1st dorsal base	232.9±2.34	231.9±2.78	234.1±2.60	232.3±2.35	231.4±2.35	878.8	0.2646	214
2nd dorsal to caudal	396.2±2.87	396.8±3.46	392.9±3.24	393.6±2.92	395.4±2.92	878.8	0.4789	215
1st dorsal spine length	100.1±1.79	100.2±2.15	100.1±2.03	98.8±1.95	100.2±1.92	874.6	0.1213	196
2nd dorsal length	107.7±2.00	109.1±2.30	109.3±2.23	109.9±1.97	107.6±1.99	878.2	0.1297	211
Anal length	105.2±1.88	105.2±2.27	105.6±2.12	103.9±1.88	103.7±1.90	879.2	0.1333	211
Pectoral length	376.2±5.61	383.5±6.74	380.0±6.38	378.0±5.76	378.5±5.76	2.9407(log)	833.9	216
Body depth	234.2±2.59	226.5±3.06	232.2±2.89	224.8±2.73	224.8±2.64	877.9	0.2471	211
Spread caudal	263.6±5.44	269.4±5.96	268.0±8.51	272.0±4.88	275.2±4.85	884.4	0.3762	182
Maxillary length	90.3±0.81	91.5±0.95	91.8±0.90	91.6±0.81	90.4±0.82	254.2	0.3507	215
Diameter of iris	39.0±0.45	39.8±0.52	39.3±0.49	39.2±0.48	39.1±0.47	253.6	0.1015	202

ples, both in long line and in pole-and-line. But when we compare the different gear samples, we cannot find the significant difference between them and the yearly tendency are not recognized in the adjusted means.

The spread caudal shows differences for samples from the two different gears. However, within samples of the same gear no differences are observed, i.e. deep-swimming albacore have a little higher spread caudal than the surface-swimming albacore.

In the other 13 characters, the differences are small.

It is noted that the morphometrical characteristics of the albacore under 70 cm. body size differ in the regression coefficients with those over 75 cm., while in the comparison of the same size samples and of the albacore over 75 cm. taken by two different gears, the difference is not recognized in the regression coefficients but in the adjusted means. The difference of regression coefficients seems to be affected by the size-composition.

But when we discuss about the albacore over 75 cm. body size, since the regression coefficients do not show the significant difference, we can obtain a straight line graph for each character.

In many characters the differences among two groups are little, and we may say that the morphometrical characteristics of the albacore taken from the same area by two kinds of fishery have a great similarity.

If these two groups of albacore could belong to the same population, morphometrical differences recognized in a few characters must be produced by the difference in their ecological and/or physiological conditions. There are some positive evidences that the two groups belong to the same population, by the fact that the seasonal movement of the fishing ground of the two types of fishery is rather continuous, and the spawning ground is supposed to be at the same place in the south, beyond the Subtropical Convergence.

The problem whether or not these differences found among the two groups from the Northwest Pacific have to be recognized as the population difference, will be decided more exactly when we could compare more groups caught from various parts in the Indo-Pacific regions.

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